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Effects of continuous (CPAP) and bi-level positive airway pressure (BiPAP) on extravascular lung water after extubation of the trachea in patients following coronary artery bypass grafting

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Abstract *Objective:* To evaluate the effects of continuous positive airway pressure (CPAP) and bi-level positive airway pressure (BiPAP) on extravascular lung water during weaning from mechanical ventilation in patients following coronary artery bypass grafting.
Design: Prospective, randomized clinical study.
Setting: Intensive care unit at a university hospital.
Patients: Seventy-five patients following coronary artery bypass grafting.
Interventions: After extubation of the trachea, patients were treated for 30 min with CPAP via face mask ($n = 25$), with nasal BiPAP ($n = 25$), or with oxygen administration via nasal cannula combined with routine chest physiotherapy (RCP) for 10 min ($n = 25$).
Measurements and results: Extravascular lung water (EVLW), pulmonary blood volume index (PBVI) and cardiac index (CI) were obtained during mechanical ventilation (T1), T-piece breathing (T2), interventions (T3), spontaneous breathing 60 min (T4) and 90 min (T5) after extubation of the trachea using a combined dye-thermal dilution method. Changing from mechanical ventilation to T-piece breathing did not show any significant differences in EVLW between the three groups, but a significant increase in PBVI from 155 ± 5 ml/m^2 to 170 ± 4 ml/m^2 could be observed in all groups ($p < 0.05$). After extubation of the trachea and treatment with BiPAP, PBVI decreased significantly to 134 ± 6 ml/m^2 ($p < 0.05$). After treatment with CPAP or BiPAP, EVLW did not change significantly in these groups (5.5 ± 0.3 ml/kg vs 5.0 ± 0.4 ml/kg and 5.1 ± 0.4 ml/kg vs 5.7 ± 0.4 ml/kg). In the RCP-treated group, however, EVLW increased significantly from 5.8 ± 0.3 ml/kg to 7.1 ± 0.4 ml/kg ($p < 0.05$). Sixty and 90 min after extubation, EVLW stayed at a significantly higher level in the RCP-treated group (7.5 ± 0.5 ml/kg and 7.4 ± 0.5 ml/kg) than in the CPAP-(5.6 ± 0.3 ml/kg and 5.9 ± 0.4 ml/kg) or BiPAP-treated groups (5.2 ± 0.4 ml/kg and 5.2 ± 0.4 ml/kg). No significant differences in CI could be observed within the three groups during the time period from mechanical ventilation to 90 min after extubation of the trachea.
Conclusions: Mask CPAP and nasal BiPAP after extubation of the trachea prevent the increase in extravascular lung water during weaning from mechanical ventilation. This effect is seen for at least 1 h after the discontinuation of CPAP or BiPAP treatment.

Further studies have to evaluate the clinical relevance of this phenomenon.

Key words Weaning · CPAP · BiPAP · Extravascular lung water · Cardiac surgery

Introduction

Postoperative weaning from mechanical ventilation in patients after coronary artery bypass grafting is frequently associated with complications. Changing from controlled mechanical positive-pressure ventilation to spontaneous breathing is accompanied by alterations in intrathoracic pressure and in lung volume [1, 2]. Generally, the alteration from mechanical ventilation to spontaneous breathing is characterized by a rapid decrease in intrathoracic pressure and an increase in abdominal pressure [2, 3]. Thus, the intrathoracic blood volume, which is the total blood volume of the lungs, heart and the large intrathoracic vessels, and the pulmonary blood volume increase. These changes induce complex cardiopulmonary interactions [4, 5], which result in an increase in left venticular preload and afterload and an impairment of left venticular function associated with the risk of increased extravascular lung water and the development of pulmonary oedema [2, 6]. Since left ventricular function in patients following coronary artery bypass grafting is frequently impaired, these patients have a relatively high risk of weaning failure [2, 6].

Continuous positive airway pressure (CPAP) and bi-level positive airway pressure (BiPAP) by mask are used in the treatment of patients with chronic pulmonary disease and acute respiratory failure to avoid intubation [7–11]. CPAP and BiPAP can improve pulmonary oxygen transfer by reestablishing functional capacity [12–15]. The aim of our study was to investigate whether treatment with mask CPAP or BiPAP for 30 min after extubation of the trachea prevents the increase in extravascular lung water (EVLW) due to an increase in pulmonary interstitial pressure, thus reducing the risk of pulmonary congestion and weaning failure in patients following coronary revascularisation.

Material and methods

Patients

After approval by the local Ethics Committee and after informed consent had been obtained from each patient, 75 patients were included in the study. All patients underwent coronary artery bypass grafting. They suffered from coronary artery disease with stenosis greater than 75% of either the left anterior descending or the circumflex artery, which was documented by preoperative coronary artery catheterisation. In all patients, preoperative echocardiography studies showed normal cardiac valve function. Lack of regular sinus rhythm during the weaning period was an exclusion criterion for the study. Further exclusion criteria were abdominal aortic aneurysm, peripheral arterial occlusive disease, pulmonary arterial hypertension, iodine allergies and pre-existing pulmonary disease as determined by clinical examination, chest radiography, lung function tests and arterial blood gases. The demographic data of the patients are listed in Table I.

In all patients, coronary artery bypass surgery and anaesthetic management were performed uniformly according to standard procedures. For oral premedication, patients were administered dipotassium clorazepate 0.3 mg/kg in the evening, and flunitrazepam 0.03 mg/kg in the morning, before surgery. Fentanyl (10–15 μg/kg), flunitrazepam (5–10 μg/kg) and etomidate (0.2 mg/kg) were used for the induction of anaesthesia. In order to facilitate tracheal intubation (endotracheal tube I.D. 8.5 mm), pancuronium (0.1 mg/kg) was administered. Anaesthesia was maintained with additional doses of fentanyl and flunitrazepam. After tracheal intubation, patients were ventilated with an inspired oxygen to nitrous oxide ($O_2:N_2O$) mixture of 1:1 at a tidal volume and ventilatory rate adequate to achieve normoventilation. Cardiopulmonary support was delivered using a pulsatile regimen with flow rates of 1.8 l/min per m^2 during normothermia and 1.1 l/min per m^2 during hypothermia. During cardiopulmonary bypass, the body core temperature was decreased to 27.5 ± 0.8 °C. Weaning from cardiopulmonary support was started after rewarming to the normal body core temperature. Postoperatively, all patients were mechanically ventilated in the Intensive Care Unit until complete haemodynamic stability and final rewarming was achieved.

Table 1 Demographic data

	Routine chest physiotherapy (RCP) [$n = 25$]	Continuous positive airway pressure (CPAP) [$n = 25$]	Bi-level positive airway pressure (BiPAP) [$n = 25$]
Male/female	23/2	21/4	23/2
Age (year)	60.5 ± 7.5	63.0 ± 7.0	62.6 ± 7.5
Height (cm)	170.1 ± 6.0	170.7 ± 7.0	171.3 ± 6.0
Weight (kg)	76.1 ± 9.0	76.5 ± 9.0	77.4 ± 8.0
Aortic cross-clamp time (min)	53.9 ± 15.0	54.5 ± 12.5	56.8 ± 12.0

Data are mean ± standard deviation

Measurements

After the induction of anaesthesia, a central venous line was placed into the right internal jugular vein. Furthermore, a 3Fr combined fiberoptic-thermistor catheter (pulsiocath PV2023; Pulsion, Munich, Germany) was introduced via a 4 Fr introducer sheath into the right femoral artery and connected to an integrated fiberoptic monitoring system (COLD Z-021, Pulsion, Munich, Germany). This system records dye and thermodilution curves in the femoral artery after central venous injection of cooled indocyanine green dye (10 ml, 2.5 mg/ml, 0 °C–4 °C) allowing for the measurement of cardiac output (CO), mean transit time of the dye indicator (MTt_D), mean transit time of the thermal indicator (MTt_T), downslope time of the dye indicator (DSt_D), and downslope time of the thermal indicator (DSt_T) in the abdominal aorta. All measurements were made in triplicate, and the mean was calculated and used for statistical evaluation. From these parameters, intrathoracic blood volume ($ITBV = CO \times MTt_D$), intrathoracic thermal volume ($ITTV = CO \times MTt_T$), and pulmonary blood volume ($PBV = CO \times DSt_D$) were calculated as described by others [16–21]. Calculation of extravascular lung water ($EVLW = ITTV - ITBV$) was based on the assumption that the dye remains in the intravascular system during the first passage, while the cold diffuses into the extravascular space [16]. CO and PBV are related to body surface area and are thus presented as the indices CI and PBVI; EVLW is related to body weight.

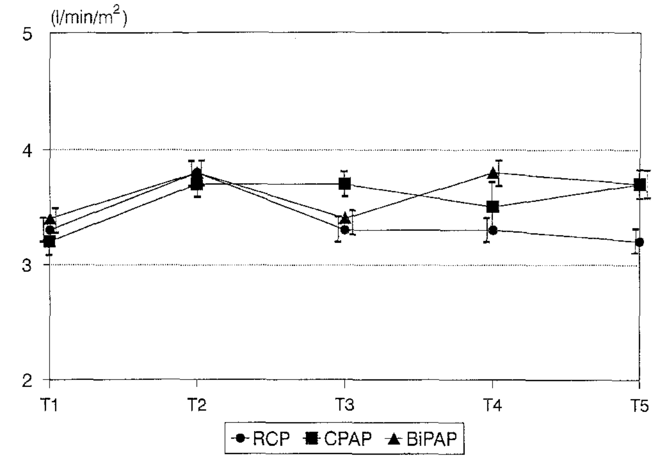

Fig. 1 Alterations of cardiac index (CI) in the groups treated with routine chest physiotherapy (RCP), continuous (CPAP) and bi-level positive airway pressure (BiPAP) during mechanical ventilation (T1), after spontaneous T-piece breathing for 30 min (T2), after extubation of the trachea and different ventilatory support modes for 30 min (T3), 60 (T4) and 90 min (T5) after extubation of the trachea

Clinical study protocol

All variables were recorded at five time points of measurements (T1–T5). When the measurements started, all patients were mechanically ventilated with a Siemens 900 C ventilator in the controlled mode with the following setting (T1): Vt 10 ml/kg; inspiration : expiration 1:2; respiratory rate 12–14/min; fractional inspired oxygen (FIO_2) 0.3; positive end-expiratory pressure (PEEP) 5 cm H_2O. The initiation of weaning required that the patients fulfilled the standard clinical criteria for weaning including haemodynamic stability, normothermia, satisfactory alertness, and PaO_2 values greater than 70 mmHg. Weaning from mechanical ventilation was started 10–14 h after coronary revascularisation by spontaneous breathing via the endotracheal tube connected to a T-piece (6 l oxygen/min). In all patients, T-piece breathing was maintained for 30 min (T2). After extubation of the trachea, patients were randomly assigned to one of three ventilatory support modes ($n = 25$ in each group) for 30 min (T3): oxygen via nasal cannula (6 l/min) and routine chest physiotherapy (RCP) for 10 min; CPAP via face mask with the CPAP system (CPAP FDF 2/G.V.V, Dräger AG, Lübeck, Germany) set at 7.5 cmH_2O and at FIO_2 0.5 (CPAP); BiPAP (BiPAP S/T Ventilatory Support System, Respironics Inc., Murrysville, PA) via nasal mask with an inspiratory positive airway pressure set at 10 cmH_2O and an expiratory positive airway pressure set at 5 cmH_2O. All BiPAP patients received 10 l/min oxygen via the nasal mask. After these ventilatory maneuvers, 6 l/min oxygen was offered to all patients via nasal cannula for 30 (T4) and 60 min (T5). The weaning process was monitored by pulse oximetry, electrocardiographic recording and the continuous measurement of arterial pressures. In patients receiving catecholaminergic support, the amount of catecholamines was not changed during the entire study period. All other aspects of patient care were identical, especially postoperative analgesia. None of the patients required reintubation following extubation of the trachea.

Statistical analysis

The statistical analysis was performed using an analysis of variance (ANOVA) for repeated measures, followed by a Wilcoxon test for paired observations. Comparisons between groups were evaluated using an ANOVA followed by Scheffé's comparison of means. All the data presented are means ± standard deviation. Differences were considered to be significant at $p < 0.05$.

Results

Cardiac index

The changes of CI during weaning are shown in Fig. 1. The alterations of CI values during mechanical ventilation (T1), T-piece breathing (T2), the three ventilatory support modes (T3), 60 min after extubation of the trachea (T4) and 90 min after tracheal extubation (T5) did not show any significant differences in CI within and among the RCP-, CPAP- and BiPAP-treated groups.

Pulmonary blood volume index

During mechanical ventilation (T1), the values of PBVI were comparable in all groups (RCP: 152 ± 5 ml/m^2; CPAP: 160 ± 4 ml/m^2; BiPAP: 154 ± 6 ml/m^2). After changing to T-piece breathing (T2), PBVI (RCP: 169 ± 6 ml/m^2; CPAP: 173 ± 5 ml/m^2; BiPAP: 169 ± 5 ml/m^2) increased significantly ($p < 0.05$) in all three groups. During treatment with the three different ventilatory modes (T3), a significant decrease in PBVI (RCP: 159 ± 6 ml/m^2; CPAP: 168 ± 7 ml/m^2; BiPAP: 134 ± 5 ml/m^2) could only be observed in the BiPAP-treated group ($p < 0.05$). Sixty and 90 min after

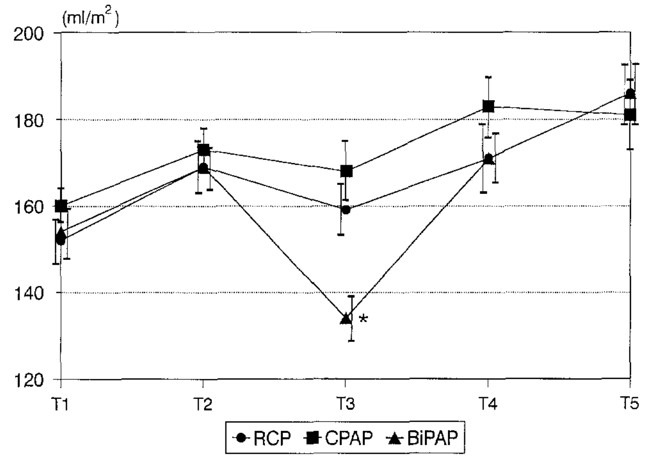

Fig. 2 Alterations of pulmonary blood volume index (PBVI) in the groups treated with routine chest physiotherapy (RCP), continuous (CPAP) and bi-level positive airway pressure (BiPAP) during mechanical ventilation (T1), after spontaneous T-piece breathing for 30 min (T2), after extubation of the trachea and different ventilatory support modes for 30 min (T3), 60 (T4) and 90 min (T5) after extubation of the trachea; *$p < 0.05$ vs. RCP- and CPAP-treated group

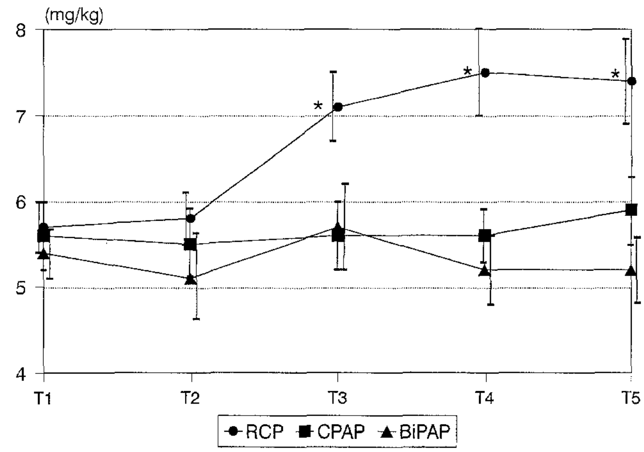

Fig. 3 Alterations of extravascular lung water (EVLW) in the groups treated with routine chest physiotherapy (RCP), continuous (CPAP) and bi-level positive airway pressure (BiPAP) during mechanical ventilation (T1), after spontaneous T-piece breathing for 30 min (T2), after extubation of the trachea and different ventilatory support modes for 30 min (T3), 60 (T4) and 90 min (T5) after extubation of the trachea; *$p < 0.05$ vs. CPAP- and BiPAP-treated group

extubation of the trachea (T4 and T5), PBVI did not change significantly in the RCP- and CPAP-treated groups (RCP: 171 ± 8 ml/m^2 and 186 ± 7 ml/m^2; CPAP: 183 ± 7 ml/m^2 and 181 ± 8 ml/m^2; BiPAP: 171 ± 6 ml/m^2 and 186 ± 7 ml/m^2). In contrast, at T3 the PBVI value was measured to be at a significantly lower level ($p < 0.05$) in the BiPAP-treated group than in the CPAP- or RCP-treated group and only increased 60 min after extubation of the trachea (Fig. 2).

Extravascular lung water

The alterations of EVLW values are shown in Fig. 3. Changing from mechanical ventilation (T1) to T-piece breathing (T2) did not show any significant differences in EVLW among the three groups (RCP: 5.7 ± 0.3 ml/kg and 5.8 ± 0.3 ml/kg; CPAP: 5.6 ± 0.4 ml/kg and 5.5 ± 0.4 ml/kg; BiPAP: 5.4 ± 0.3 ml/kg and 5.1 ± 0.5 ml/kg). After extubation of the trachea and treatment with CPAP and BiPAP (T3), EVLW (CPAP: 5.6 ± 0.4 ml/kg; BiPAP: 5.7 ± 0.5 ml/kg) remained at a constant level up to the end of the study (T4, T5). By contrast, EVLW increased significantly from 5.8 ± 0.3 ml/kg (T2) to 7.1 ± 0.4 ml/kg (T3) in the RCP-treated group and remained (7.5 ± 0.5 ml/kg and 7.4 ± 0.5 ml/kg) at a significantly higher level ($p < 0.05$) 60 (T4) and 90 min after extubation of the trachea (T5) than in the CPAP- (5.6 ± 0.3 and 5.9 ± 0.4 ml/kg) or BiPAP-treated group (5.2 ± 0.4 ml/kg and 5.2 ± 0.4 ml/kg).

Discussion

We tested the effects of treatment with CPAP or BiPAP on EVLW during weaning from mechanical ventilation in patients following coronary artery bypass grafting. Weaning from controlled mechanical ventilation is associated with complex cardiopulmonary interactions [5]. Due to sub-atmospheric intrathoracic pressures during spontaneous inspiration, an increase in systemic venous return induces an increase in right ventricular end-diastolic volume [1]. This, however, results in an increase in right ventricular stroke volume and, thus, in an increase in left ventricular preload [4]. Furthermore, left ventricular compliance during weaning from mechanical ventilation may be reduced in patients following coronary artery bypass grafting due to a preoperatively impaired left ventricular function and/or impairment of left ventricular function after cardiopulmonary bypass [22, 23]. Several studies have suggested that cardiac dysfunction itself may impair weaning from mechanical ventilation due to the development of pulmonary oedema [2, 6]. An increased permeability due to an endothelial cell injury may also lead to pulmonary congestion and oedema after cardiopulmonary bypass [24]. Obviously, patients following coronary revascularisation have a relatively high risk of weaning failure [2, 6]. In these patients, weaning failure secondary to the acute onset of pulmonary oedema has been reported [2, 6]. In addition, previous studies have not found an optimal treatment modality to prevent the postoperative development of pulmonary congestion and weaning failure [25, 26].

The major advantages of CPAP and BiPAP are the improvement of functional residual capacity and of oxygen transfer [12, 13]. These effects of CPAP and BiPAP can be achieved equally well with CPAP via face mask or nasal mask [11, 27]. In the past, these methods were used especially in the treatment of obstructive sleep apnoea syndrome [28–30]. CPAP and BiPAP have also been beneficial to patients with chronic pulmonary disease and in home care [8, 9, 14]. Moreover, it has been demonstrated that CPAP and BiPAP may be helpful in avoiding endotracheal intubation in patients with acute respiratory failure, in the prevention of pneumonia and in the treatment of atelectasis [10, 11, 31, 32]. Despite an increase of reports in the literature about CPAP and BiPAP, there is no study dealing with the effects of these modes on EVLW.

In a prospective open clinical study, we therefore measured the EVLW using a combined dye-thermal dilution method. This technique for the determination of thoracic intravascular and extravascular fluid volumes is based on the measurement of the mean transit times for thermal and dye indicators and of the decay time volumes calculated from the indicator curves [16–21]. Previous studies have demonstrated clearly that the technique used in the present study is a reliable and established method [17, 33, 34]. The statistical analysis of the data showed that the patient groups were comparable in terms of age aortic cross-clamp time, duration of cardiopulmonary bypass, preoperative and postoperative left ventricular function and inotropic support. Knowing the influence on postoperative respiratory function in patients receiving inotropic therapy, the amount of catecholamines was not changed during the entire study period. The infusion schedule was standardized in all patients. Furthermore, urine output and bleeding were balanced.

Our study showed that an increase in EVLW was only observed in the patient group treated with oxygen administration via nasal cannula combined with RCP. In contrast, CPAP via face mask and nasal BiPAP over a period of 30 min after extubation of the trachea prevented the increase in EVLW during weaning from mechanical ventilation. This effect remained stable for at least 1 h after the discontinuation of CPAP or BiPAP treatment. Furthermore, nasal BiPAP reduced the PBV during the weaning procedure. During CPAP and BiPAP treatment we could not find any cardiocirculatory impairment, and no differences in CI were observed between the CPAP-, BiPAP- and RCP-treated groups. The positive effects of CPAP and BiPAP on EVLW may be explained by the fact that the extent of EVLW depends on oncotic, hydrostatic and interstitial pressure. Both CPAP and BiPAP treatments increase intrathoracic pressure and, thus, intrathoracic interstitial pressure. Obviously, this increased interstitial pressure due to CPAP or BiPAP is sufficient to prevent an increase in EVLW without cardiocirculatory impairment in patients with increased permeability due to capillary leakage after cardiopulmonary bypass.

Our results are in accordance with the study by Nawada et al. [35]. They found an increase in EVLW in spontaneously breathing patients suffering from left-sided heart failure. In this study, the average value of EVLW was 3.0 ± 1.4 ml/kg in subjects with normal cardiac function, 4.3 ± 1.7 ml/kg in New York Heart Association (NYHA) class I patients, 4.8 ± 2.4 ml/kg in NYHA class II patients and 9.4 ± 5.4 ml/kg in NYHA class III patients. Hachenberg et al. have described similar results when studying patients on mechanical ventilation 4 h after aortocoronary bypass [17]. They measured EVLW values of 6.4 ± 2.1 ml/kg. In patients on mechanical ventilation after cardiopulmonary bypass, Boldt et al. also reported EVLW values of 5.8 ± 0.3 ml/kg [36]. However, the results of our study explain the positive effects of mask CPAP or BiPAP in the treatment of pulmonary oedema that were observed by other authors [37, 38].

In summary, the results of the present study demonstrate that CPAP via face mask or nasal BiPAP over a period of 30 min after extubation of the trachea prevent an increase in EVLW during weaning from mechanical ventilation, and this effect remained for at least 1 h after the discontinuation of treatment. We therefore conclude that treatment with mask CPAP or nasal BiPAP immediately after extubation of the trachea may reduce complications in weaning from mechanical ventilation in patients following coronary artery bypass grafting or in patients with impaired left ventricular function or increased permeability due to capillary leakage.

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