*Acta Anaesthesiol Scand 2000; **44**: 75–81*
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ACTA ANAESTHESIOLOGICA SCANDINAVICA
ISSN 0001-5172

Effects of conventional physiotherapy, continuous positive airway pressure and non-invasive ventilatory support with bilevel positive airway pressure after coronary artery bypass grafting

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Background: Coronary artery bypass graft (CABG) surgery with the use of mammary arteries is associated with severe alteration of lung function parameters. The purpose of the present study was to compare the effect on lung function tests of conventional physiotherapy using incentive spirometry (IS) with non-invasive ventilation on continuous positive airway pressure (CPAP) and with non-invasive ventilation on bilevel positive airway pressure (BiPAP or NIV-2P).
Methods: Ninety-six patients were randomly assigned to 1 of 3 groups: NIV-2P (1 h/3 h), CPAP (1 h/3 h) and IS (20/2 h). Pulmonary function tests and arterial blood gases analyses were obtained before surgery. On the 1st and 2nd postoperative days, these parameters were collected together with cardiac output and calculation of venous admixture.
Results: For the 3 groups a severe restrictive pulmonary defect was observed during the 1st postoperative day. On the 2nd postoperative day, in opposition to IS, intensive use of CPAP and NIV-2P reduced significantly the venous admixture ($P<0.001$) and improved VC, FEV_1 and PaO_2 ($P<0.01$).
Conclusion: We conclude that preventive use of NIV can be considered as an effective means to decrease the negative effect of coronary surgery on pulmonary function.

Received 1 March, accepted for publication 3 July 1999

Key words: Coronary artery bypass graft; non invasive ventilation; CPAP; BiPAP.

SURGICAL myocardial revascularization with the use of mammary arteries is often complicated by significant pulmonary dysfunction that lasts for a few days after surgery (1–8). Multiple factors are involved in the deterioration of the pulmonary function including: pleural opening, phrenic nerve alteration, and pain. The use of mammary and gastroepiploic arteries for myocardial revascularization is associated with an increased perturbation of the respiratory mechanics compared to the use of saphenous vein grafts.

Incentive spirometry (IS) and continuous positive airway pressure (CPAP) have been reported to reduce atelectasis and increase PaO_2 after thoracic or abdominal surgery (9–13). The promising results of non-invasive ventilation with two levels of pressure (NIV-2P) in acute respiratory disease and cardiogenic pulmonary edema (14–21) raises the question of its effectiveness after surgery.

The aim of our study was to evaluate the effect of NIV-2P on gas exchanges, venous admixture, lung function tests and cardiac output after coronary artery bypass graft (CABG) surgery as compared to IS and CPAP.

Patients and methods

Patients

Ninety-six patients undergoing elective CABG with the use of mammary arteries were included in the study. Their preoperative characteristics are presented in Table 1. These operations were performed with sternotomy and cardiopulmonary bypass.

All patients were mechanically ventilated by means of a Servo 900c ventilator (Siemens, Solna-Sweden) with a tidal volume of 8–10 ml/kg, a respiratory rate adapted for a $PaCO_2$ of $\pm$35 mmHg, a positive end-expiratory pressure (PEEP) of 5 cm H_2O and a maximal inspiratory pressure of 20 cm H_2O. The ventilator parameters were modified to normalize oxygenation and acid-base status. As a routine protocol, patients were monitored postoperatively by means of a pulmonary and a radial artery catheter. After extubation,

Table 1

Preoperative patient data.

	IS	CPAP	NIV-2P	*P* value
Age (yr)	63±8	65±8	64±9	NS
Sex M/F	25/5	30/3	30/3	NS
Weight (kg)	76±12	81±11	77±16	NS
Height (cm)	169±8	170±10	169±10	NS
VC (ml)	3568±931	3438±838	3487±576	NS
FEV_1 (ml)	2601±700	2535±622	2678±767	NS
pH	7.40±0.01	7.40±0.01	7.41±0.01	NS
$PaCO_2$ (mmHg)	39±3	38±4	38±4	NS
PaO_2 (mmHg)	78±10	76±12	81±10	NS

VC=vital capacity; FEV_1=Forced expiratory volume in 1 s.

patients received analgesic medication (propacetamol, 2 g IV) according to their needs up to a maximum of 12 g/24 h.

Patients with unstable cardiac status, severe cardiac dysrhythmias, intubation time longer than 24 h, bronchoemphysema status and severe atelectasis were excluded from the study. The protocol was approved by the institutional Human Ethics Committee and patients gave their informed consent to participate in the study.

Methods

After extubation, patients were randomly assigned to 3 groups:

- In group 1, patients were treated with routine chest physiotherapy (RCP) (coughing exercices, aerosoltherapy, mobilization) and IS (Coach – volume) 20/2 h.
- In group 2, patients were treated with RCP and CPAP (REM+ control, SEFAM, Villers Les Nancy, France), 5cm H_2O, 1 h/3 h.
- In group 3, patients were treated with RCP and NIV-2P (VENTIL+, SEFAM) with the expiratory positive airway pressure (EPAP) set at 5 cm H_2O and a peak inspiratory positive airway pressure (IPAP) at 12 cm H_2O 1 h/3 h.

The study was started 4 h after extubation.

Ventilatory support system

CPAP is a spontaneous ventilatory mode maintaining a supra-atmospheric pressure in the lung. NIV-2P is a barometric ventilatory mode the action of which is determined by the difference between IPAP and EPAP. In the spontaneous mode, the unit switches from IPAP and EPAP when the patient's inspiratory flow reaches 20 ml/s. The NIV-2P system is applied with a comfortable oronasal mask (Bird, Palm Springs, California). The respirator is able to self-regulate the 2 levels of pressure even in the presence of slight air leaks.

Cardiac output measurement

A pulmonary artery catheter (Swan-Ganz, Baxter/Edwards, Irvine, California) was inserted preoperatively usually via the right internal jugular vein. Ten milliliters of glucose 5% at room temperature were injected manually with a closed injectate system and cardiac output (CO) was automatically calculated by means of a CO computer (Baxter/Edwards, Irvine, California) from the thermodilution curve. The injections were randomly performed during breathing and the procedure was repeated 4 times. The average of 4 measurements was calculated after rejection of the unsatisfactory curves. CO was measured before and during the treatment (45 min after the start of the treatment).

Blood gases

Blood was drawn from the radial and the pulmonary artery for gas analysis (OSM3 Hemoximeter, Copenhagen, Denmark and Chiron Diagnostics 288 Blood Gas System, Medfield, Massachusetts) on the 1st postoperative day (4 h after extubation) before and during the treatment and on the 2nd postoperative day (24 h after the first exercice). Arterial and mixed venous oxygen content were measured at a FiO_2 of 0.21.

Venous admixture was calculated with a computerized program using the formula (24):

$$Qs/Qt = CcO_2 - CaO_2 / CcO_2 - C\bar{v}O_2$$

where CcO_2=capillary oxygen content, CaO_2=arterial oxygen content and $C\bar{v}O_2$=mixed venous oxygen

Table 2

Pulmonary function tests and venous admixture

	Preop.	Day 1 before treatment	Day 1 during treatment	Day 2
VC (ml)				
IS	3568±931	1674±492*		1332±398**
CPAP	3438±838	1410±405*		1670±670**
NIV-2P	3487±943	1395±422*		1759±522**
FEV_1 (ml)				
IS	2601±701	1026±622*		884±258**
CPAP	2535±622	972±258*		1067±256**
NIV-2P	2678±767	1017±380*		1097±369**
Venous admixture (%)				
IS		17.5±8		18.9±4**
CPAP		18.7±7	16.5±3#	13.2±4##
NIV-2P		20.6±8	16.7±5#	13.1±6##

* $P<0.0001$ D1 vs Preop; ** $P<0.01$ D2 vs D1; # $P<0.01$ D1 during treatment vs D1 before treatment; ## $P<0.001$ D2 vs D1.

content; CcO_2=Hb×1.34+(PAO_2×0.0031); with PAO_2=alveolar oxygen pressure estimated by: PAO_2=FiO_2×(P barometric−47)−$PaCO_2$.

Pulmonary function tests

Vital capacity (VC) and forced expiratory volume in 1 s. (FEV_1) were measured by the same physiotherapist with a Vitalograph compact (Alfatec, Buckingham, England) in a semi-sitting position before the surgery, on the 1st postoperative day before the start of the study (4 h after extubation) and on the 2nd postoperative day (24 h after the start of the study). The best results of 3 attempts were utilized for the study. This physiotherapist was blinded to the treatment assignment.

Atelectasis

Chest X-rays obtained preoperatively and on the 1st and 2nd postoperative days were evaluated by a radiologist who was blinded to the patient's study group.

Statistics

Data are presented as mean±standard deviation (SD). For the between-groups comparison and for compari-

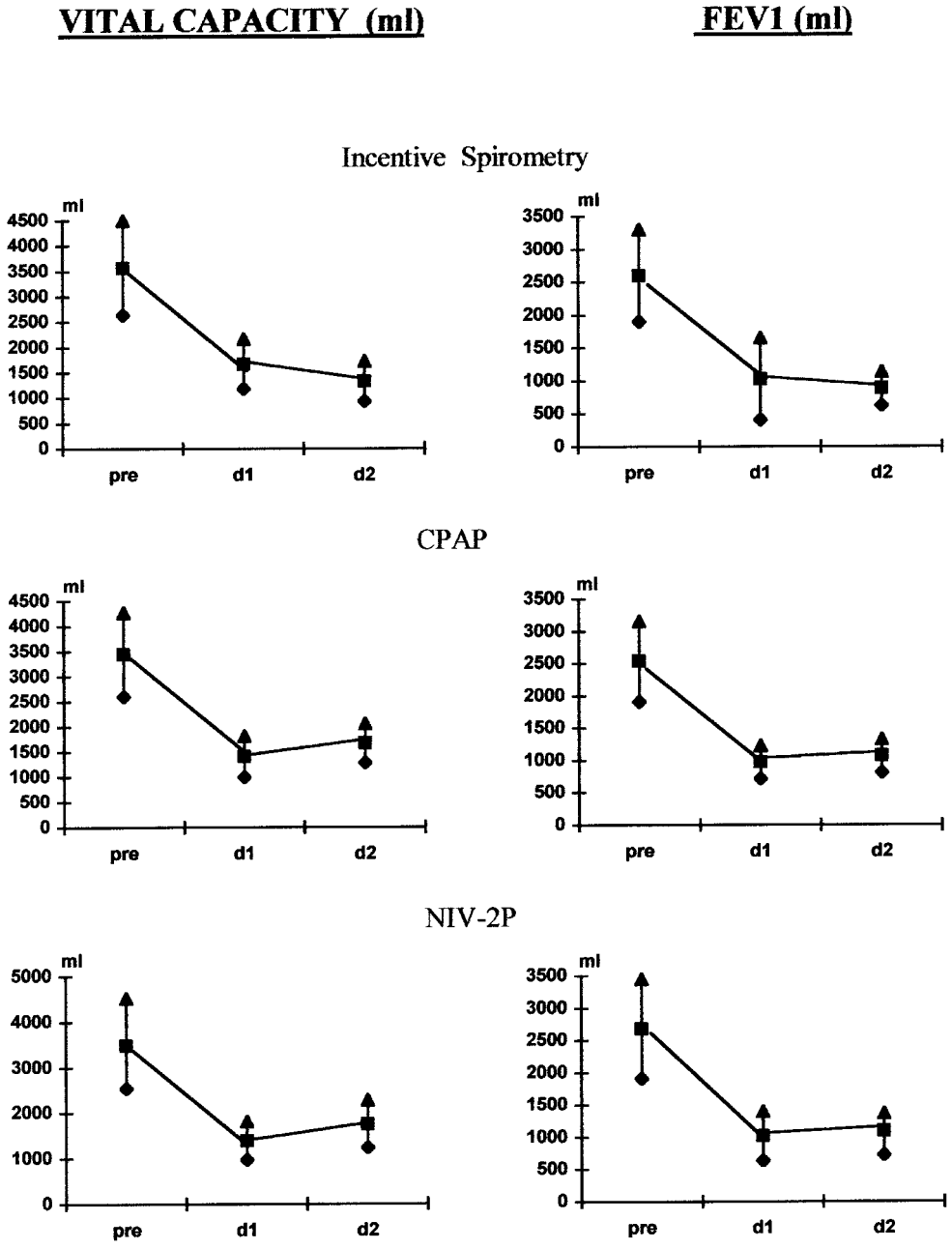

Fig. 1. Evolution of vital capacity and forced expiratory volume in 1 s.

Table 3

Comparison between groups of the evolution of VC, FEV_1 and venous admixture.

	NIV-2P	CPAP	IS
Δ VC (from preop to D1)	−2092±817 ml	−2098±703 ml	−1894±712 ml
Δ VC (from D1 to D2)	364±312 ml	260±281 ml	−342±313 ml*
Δ FEV_1 (from preop to D1)	−1660±699 ml	−1563±510 ml	−1575±601 ml
Δ FEV_1 (from D1 to D2)	80±136 ml	95±151 ml	−142±188 ml*
Δ venous admixture (from D1 to D2)	−7.5±6.7%	−5.5±4.1%	1.4±4.6%*

Δ=change
* $P<0.001$ IS vs NIV-2P and CPAP.

son at the different times, an analysis of variance (ANOVA) was used. If a significant difference was noted, pairwise comparisons were performed by the Student-Newman-Keuls test to account for multiple comparisons. *P* values below 0.05 were considered significant.

Results

Patients

Six patients (two in group 1, two in group 2 and two in group 3) were excluded for non conformity with the study protocol (6 for intubation >24 h).

Preoperative data of the 3 groups were similar with regard to age, sex, weight, height, pulmonary function tests and arterial blood gases (Table 1).

Pulmonary function tests

In the 3 groups, the deterioration of the respiratory parameters (VC and FEV_1), as detailed in Table 2 and Fig. 1, was highly significant on the 1st postoperative day as compared to preoperative values ($P<0.0001$). Despite an intensive use of incitative spirometry after extubation, patients in group 1 continued to deteriorate on the 2nd postoperative day ($P<0.01$). VC on the 1st postoperative day decreased more than 53% and even 63% on the 2nd postoperative day. The evolution of FEV_1 was similar with a decrease of 61% and 66%. Intensive use of CPAP or NIV-2P after extubation allowed a significant reduction of the severe restrictive syndrome observed on the 1st postoperative day ($P<0.01$).

In patients treated with CPAP, VC decreased 59% on the 1st postoperative day and 51% on the 2nd postoperative day. The drop of VC for patients treated with NIV-2P was 60% on the 1st day and 50% on the 2nd day. The improvement of FEV_1 was slightly lower.

When comparing changes in VC between groups, no difference was noted on the 1st postoperative day; on the 2nd day IS patients differed significantly from both NIV-2P and CPAP patients (Table 3). No difference was observed between CPAP and NIV-2P. The same observation applies to results of FEV_1.

Atelectasis

Thirty percent of patients treated with incentive spirometry and 15% of patients treated with CPAP or NIV-2P developed mild or moderate atelectasis on the 2nd postoperative day.

Venous admixture

A significant intra-pulmonary shunt, similar in the 3 groups, was observed on the 1st postoperative day: 17.5±8% in the IS group, 18.7±7% in the CPAP group and 20.6±12% in the NIV-2P group (Table 2 and Fig. 2). However, the evolution was totally different for patients treated with incentive spirometry in whom an increase of the venous admixture was observed ($P<0.01$) with time as opposed to patients treated with CPAP and NIV-2P in whom a reduction from 18.7% to 13.2% ($P<0.001$) with CPAP and from 20.6%

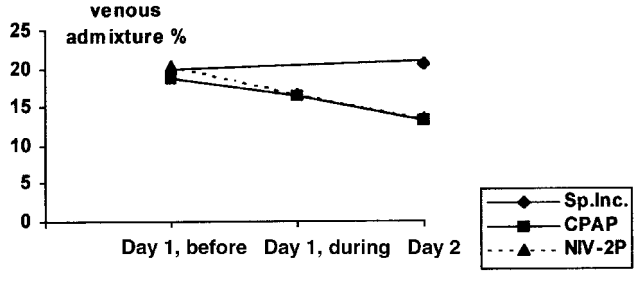

Fig. 2. Evolution of venous admixture.

Table 4

Blood gas and cardiac output.

	Preop.	Day 1 before treatment	Day 1 during treatment	Day 2
pH				
Incentive spirometry (IS)	7.41±0.02	7.41±0.01	7.41±0.01	7.44±0.01
CPAP	7.40±0.01	7.41±0.02		7.41±0.01
NIV-2P	7.41±0.01	7.40±0.02	7.41±0.01	7.43±0.02
PaO_2 (mmHg)				
IS	78±10*	65±12		63±9
CPAP	76±12*	63±9	65±8**	66±9**
NIV-2P	81±10*	66±11	70±12**	69±12**
$PaCO_2$ (mmHg)				
IS	40±3*	34±4		33±4
CPAP	38±4*	34±4	34±3	32±4
NIV-2P	38±4*	35±5	33±4	33±4
Respiratory rate (RR)				
IS				
CPAP		22±4	23±4	
NIV-2P		21±5	19±4#	
Cardiac output (CO) ml/min				
IS				
CPAP		5897±963	5680±989	
NIV-2P		5806±973	5209±980#	

* $P<0.001$ preop vs D1 and D2; $P<0.01$ D1 during treatment and D2 vs D1 before treatment; $P<0.01$ D1 before treatment vs D1 during treatment.

to 13.1% with NIV-2P was noted ($P<0.001$). This decrease of venous admixture was already observed during the first use of CPAP and NIV-2P (Table 2). Results obtained with NIV-2P seem slightly better than when CPAP is used, but the difference was not significant.

Blood gases (Table 4)

For the 3 groups, pH remained remarkably stable during the first 2 postoperative days in spite of a slight hypocapnia.

PaO_2 decreased significantly on the 1st postoperative day in the 3 groups ($P<0.001$). This drop was still present on the 2nd day for the patients treated with IS; however, patients of the other 2 groups had a slightly improved PaO_2 ($P<0.01$).

During CPAP, PaO_2 increased while $PaCO_2$ and respiratory rate remained stable. However, with NIV-2P, PaO_2 increased, $PaCO_2$ remained stable but respiratory rate decreased slightly (23±4 vs 19±4, $P<0.01$).

Cardiac output (Table 4)

NIV-2P had a little higher influence on cardiac output than CPAP (−11% with NIV-2P vs −4% with CPAP, $P<0.01$).

Stay in the ICU (Table 5)

Between these 3 small groups, no significant difference was observed.

Discussion

The association of CABG surgery, prolonged anesthesia and mechanical ventilation induces significant restrictive pulmonary defects that are a major cause of postoperative morbidity and sometimes mortality.

The use of mammary arteries for surgical myocardial revascularization increases the rate of postoperative pulmonary complications as compared to saphenous vein grafts use (7). As already observed by Ferdinande et al. in 1988 (3) and Oïkonen et al. in 1991 (4), our study demonstrates a large deficit of pulmonary function when mammary arteries are used as conduit for revascularization. A ±65% drop of VC and FEV_1 is observed on the 1st postoperative day. Therefore, early intensive respiratory therapy is instituted in order to prevent further degradation. During normal respiration, deep intermittent breaths appear more or less every 5 min. Postoperatively, these profound breaths that allow alveolar recruitment disappear (9).

Table 5

Stay in the intensive care unit.

	NIV- 2P	CPAP	IS	*P* value
Mean±SD (h)	49.9±14.5	50.1±11.4	53.2±27.9	NS

During the first 2 postoperative days after CABG, ventilation is characterized by small tidal volumes, compensated for by an increased respiratory rate aiming to maintain a normal pH. This shallow and unvaried breathing pattern decreases tidal volume and contributes to the development of atelectasis.

The pleural opening, the complications induced by surgery (possible phrenic nerve lesion, pain), the prolonged recumbent position and the reduction of diaphragmatic movements are factors contributing to this breathing pattern, inducing a decrease of resting lung volume and a large restrictive syndrome (5).

The level of calculated venous admixture (±19%) observed on the 1st postoperative day in our study highlights the effects of volume changes on gas exchange. However, as previously described, intensive use of incentive spirometry, immediately after extubation, can not prevent progressive increase of venous admixture (17.5% to 18.9%) and a further worsening of pulmonary function tests.

Our study demonstrates that, as opposed to IS, the preventive use of CPAP or NIV-2P significantly reduces this restrictive syndrome and venous admixture.

From the 1st to the 2nd postoperative day, VC of patients treated by CPAP increases by 18% and by 26% in those treated by NIV-2P. The significant decrease of venous admixture, between day 1 and day 2 with NIV-2P and with CPAP, can be explained in part by a better arterial oxygenation, as already described by Dehaven et al. in 1985 (12) and Pennock et al. in 1991 (17). This improvement obtained with NIV-2P could be related to several factors. The use of CPAP avoids alveolar collapse and allows a better alveolar recruitment (19) without pain and without active collaboration of the patient. This beneficial effect is present during the day but also during the night, where a more important hypoventilation is observed (22).

The improvement could be somewhat better with NIV-2P than with CPAP due to a better alveolar opening and a large decrease of the work of breathing, which is suggested by the decrease of respiratory rate observed during NIV-2P without change in $PaCO_2$ (18, 21). In our observation, the inhomogeneity of improvement with NIV-2P suggests that the inspiratory pressure has to be adapted individually according to patients' compliance and comfort. Several studies suggest adjusting the level of IPAP according to the tidal volume (18, 19) or according to the electromyographic activity of the diaphragm (23).

However, NIV-2P is also associated with a significant drop of cardiac output. This higher influence of NIV-2P on cardiac output can be explained either by higher increase of intrathoracic pressures with increased repercussions on cardiac function, or by the ventilatory improvement associated with an increase of comfort, and a decrease of the work of breathing. Futher studies are required to test these hypotheses.

Conclusion

In summary, for a majority of patients undergoing CABG with the use of mammary arteries, intensive use of CPAP and especially NIV-2P, in adjunct to routine chest physiotherapy, can be considered as an effective means of limiting the deleterious consequences of surgery on pulmonary function, improving venous admixture.

Further studies, with a larger number of patients, are needed to evaluate the repercussions of this improvement of the pulmonary function with the noninvasive ventilation on ICU stay, hospital stay and the cost of care.

Analysis of the cardiac output alone does not allow conclusions to be drawn on the repercussions of NIV-2P on cardiac function. Studies evaluating the effect of different inspiratory pressure levels on cardiac volumes, pressures and function are underway.

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