Comparison of Incentive Spirometry and Intermittent Positive Pressure Breathing after Coronary Artery Bypass Graft*

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Fifty-two patients were randomized to receive either incentive spirometry (IS) or intermittent positive pressure breathing (IPPB) in addition to conventional chest physical therapy following coronary artery bypass grafting. Slow vital capacity and peak expiratory flow readings decreased rapidly and to an equal extent in both groups after surgery, and partly recovered by the sixth postoperative day (POP). Arterial Po_2 values were similar for the groups on the first three POPs. On the POPs 2, 3, and 6, the number of chest films showing atelectases as well as the number of individual patients having atelectases revealed no statistically significant differences between the two groups. Based on the three variables studied, we consider both devices equal in efficiency after coronary surgery. ***(Chest 1991; 99:60-65)***

CPT = chest physiotherapy; IS = incentive spirometry; POP = postoperative day

The value of adequate preoperative and postoperative physiotherapy (CPT) has long since been recognized.[1] After cardiac surgery, multiple factors (interstitial pulmonary edema from heart insufficiency[2] and disturbed capillary endothelium;[2,3] atelectasis promoted by decreased thoracopulmonary compliance,[4,5] pleural effusions and mediastinal hematomas,[2,5] and depressed sigh function;[6] major surgery followed by protracted intubation[3]) work in concert[2] to increase alveolar-arterial oxygen gradient and the risk of infection.

Even if the first few postoperative days cover the most vulnerable period, the detriment in pulmonary function persists into the fourth month.[4] Many of the above etiologic problems are not alleviated by CPT, but proper CPT may interrupt the vicious circle where an average patient is concerned.[5] Chest physiotherapy and so-called "stir-up" regimens are tedious in cardiac patients due to slow ambulation caused by occasional hemodynamic problems, invasive monitoring techniques, and drainage tubes. Expectations have been focused on mechanical devices, but the effectiveness of periodic intermittent positive pressure breathing (IPPB), sustained maximal inhalation (incentive spirometry [IS]), resisted exhalation (blow bottles, positive expiratory pressure), and continuous positive airway pressure (CPAP) in connection with general[6-11] as well as cardiac[5,7,11-14] surgery has been disputed.

In this study, we examined the effect of IPPB, the routine in use in our clinic, and IS given as an adjunct to conventional CPT in selected patients undergoing coronary artery bypass grafting (CABG) operations.

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Material and Methods

After approval by the Ethical Committee of the hospital, 52 consecutive, informed consenting patients (pts) scheduled for CABG during a five-month period were selected for the study (Table 1). The patients were randomly allocated to receive either IPPB or IS in addition to CPT. Exclusion criteria were age older than 70 years, weight exceeding the ideal weight by more than 20 percent,[15] history of chronic obstructive pulmonary disease (COPD), thoracic anomalies, previous thoracic operation, including CABG, signs of severe extracoronary sclerosis, unstable angina, and postoperative respirator treatment exceeding 20 h. The study formulas of those

Table 1—*Demographic and Perioperative Data of Patients Receiving Incentive Spirometry (Group IS) or Intermittent Positive Pressure Breathing (Group IPPB) after CABG

	Group IS (n = 26)	Group IPPB (n = 26)
Age, yr	55 ± 1	55 ± 1
Sex, F/M	4/22	4/22
Weight, kg	79 ± 2	78 ± 3
Height, cm	174 ± 2	172 ± 2
Smokers during the preceding year	5	7
NYHA group	3.0 ± 0.1	2.9 ± 0.1
No. of grafts	3.4 ± 0.2	3.0 ± 0.3
Duration of anesthesia, h (induction—end of surgery)	5.8 ± 0.3	5.0 ± 0.3
Cardiopulmonary bypass, h	1.8 ± 0.1	1.6 ± 0.1
Postoperative respirator treatment, h	14.9 ± 0.6	13.9 ± 0.8
Consumption of		
Fentanyl, mg	6.2 ± 0.2	5.3 ± 0.2
Oxycodone, mg	99 ± 6	102 ± 7
Diazepam, mg up to the 3 POP	17 ± 4	17 ± 3

*Values are means ± SE or number of patients.

patients who were excluded by the last criteria or died during the operation (n = 8 and 1, respectively) were immediately taken for reallocation, so that there appeared an even number of patients in both groups.

Saphenous vein aortocoronary grafts, and usually LIMA-LAD grafts were constructed under hypothermic bypass (Bentley BCM-7 membrane-capillary oxygenator). Cold cardioplegia and local pericardial cooling were used. The patients' lungs were kept deflated during the aortic clamping. Pericardiac, mediastinal, and left pleural spaces were drained, usually for two days.

A single dose of clindamycin was given at anesthesia induction. The high-dose fentanyl anesthesia was followed by IMV respiratory treatment employing 5 cm H_2O positive end-expiratory pressure (PEEP). The respiratory therapy was attended mainly by three staff anesthesiologists participating in the study. The patients were extubated, when awake, hemodynamically stable, able to normoventilate without distress, and with $PaO_2 > 10$ kPa at $FIo_2 < 0.5$. Nasogastric tubes were simultaneously removed. The patients routinely spent three days on the postcoronary ward.

One to two days preoperatively, two physical therapists instructed the patients in breathing techniques, deep diaphragmatic ventilation, and efficient coughing. The therapists guided the handling of either the IPPB or IS device. IPPB (Bennett PR2, Puritan Bennett, USA) was administered through a mouthpiece accompanied with a nose-clip or through a face mask, whichever suited the patient better, and was triggered by him. The peak airway pressure was adjusted ranging from 10 to 15 cm H_2O at each session, to result in a sufficient widening of the thoracic cage. The satisfactory effect was verified by observing the simultaneous attainment of the peak pressure and of the deep inspiration. It was the target to take a minimum of ten satisfactory inspirations in 5 to 10 minutes at each session. The IS patients used an incentive spirometer (DHD Coach, DHD Medical Products, USA) equipped with a volume-oriented goal indicator and an inspiratory flow guide to promote a slow sustained inhalation. On the day the patient was extubated, the goal was set at half of the top value measured preoperatively and it was gradually increased, under the supervision of the therapists, to the initial reading during the next four to five days. The patients aimed at a successful inhalation, exceeding 3 s in duration, and repeated it at least five times per training.

It was designed that the patients should receive IPPB no less than on four occasions daily. IS was planned to be administered at alternate waking hours. In the first postoperative days, the ward nurses aided the patients in performing the maneuvers, after which the patients performed independently. The therapists visited the patients at least once daily, and more frequently if necessary, gave conventional CPT, and also guided and assisted the patients in use of the devices. Preceding the CPT, they performed, at the bedside, the pulmonary function tests used in the study, in a recumbent, and when feasible, also in a sitting position: VC = (expiratory) slow vital capacity (Paul Buhl Wiesbaden model II, GFR); PEF = peak expiratory flow (Wright peak flow meter standard model II, UK). Two measurements were taken and the better result was recorded. The first set of measurements was done preoperatively, and the tests were repeated once daily.

A radiologist, unaware of the grouping of an individual patient, analyzed, retrospectively, posteroanterior (PA) chest films that were taken before the operation, on the evening of the operation day, thereafter daily up to the third postoperative day (3 POP) (supine projection), and on the sixth POP (upright projection). Atelectasis,[2] pulmonary infiltrations, pleural effusions, elevation of the diaphragm, and pulmonary vascularity were tabulated.

Arterial blood gas values were taken before anesthesia induction, 3 to 6 h after the end of operation, 30 min to 1 h after extubation, and thereafter at 6 AM and 6 PM as long as clinically deemed necessary (Corning 178 pH/Blood-gas analyzer, USA).

Variations in the daily number of observations are indicated in the Tables. The results are given as mean ± SE. Student's t test and χ^2 test were used to compare the parametric and nonparametric variables of the study groups, respectively. The level of statistical significance was set at $p < 0.05$.

Results

A single patient (pt) in both study groups suffered postoperative respiratory insufficiency that necessitated protracted ventilator therapy through a tracheostomy. An additional IPPB pt was put on the respirator, because of circulatory failure. The results of these three patients were recorded until they were newly connected to the ventilator. As the primary method failed, two IS patients were given IPPB and one IS and one IPPB pt received CPAP through a mask temporarily for few hours. Severe wound pain was experienced by four IS and two IPPB pts when commencing their CPT program.

The IS pts used the device on 17 ± 1 occasions and

Table 2—*Values of the Pulmonary Function Tests in Patients Receiving Incentive Spirometer (IS) or Intermittent Positive Pressure Breathing (IPPB) after CABG***

		The Day of Measurement, Postoperative				
	Preoperative	1	2	3	4	7
VC_r						
IS	3,692 ± 132 (25)	1,465 ± 132 (23)	1,290 ± 97 (24)	1,441 ± 114 (17)	1,555 ± 131 (11)	2,108 ± 128 (12)
IPPB	3,527 ± 203 (26)	1,421 ± 139 (24)	1,438 ± 139 (24)	1,713 ± 170 (15)	1,915 ± 193 (16)	2,469 ± 343 (8)
VC_s						
IS	3,932 ± 163 (25)	. . .	. . .	1,836 ± 239 (11)	1,920 ± 125 (15)	2,404 ± 654 (21)
IPPB	3,769 ± 204 (26)	. . .	. . .	1,833 ± 218 (12)	1,971 ± 154 (19)	2,543 ± 186 (22)
PEF_r						
IS	496 ± 17 (25)	248 ± 18 (23)	203 ± 16 (24)	230 ± 16 (18)	275 ± 23 (11)	351 ± 24 (12)
IPPB	488 ± 23 (26)	238 ± 20 (23)	221 ± 18 (24)	261 ± 22 (15)	283 ± 23 (16)	388 ± 65 (6)
PEF_s						
IS	524 ± 18 (25)	. . .	. . .	288 ± 30 (10)	292 ± 15 (15)	405 ± 22 (21)
IPPB	526 ± 21 (26)	. . .	. . .	275 ± 28 (12)	314 ± 22 (19)	405 ± 22 (23)

*Values are means ± SE. VC = slow vital capacity, ml; PEF = peak expiratory flow, L/min; r = recumbent; s = sitting. The number of observations is in parentheses.

the IPPB pts used the device on 9 ± 1 occasions during the first and second POP, *ie*, on 8.5 and 4.6 occasions/day, respectively. The therapists paid 5 ± 0.4 and 4 ± 0.4 CPT visits during the same period, respectively, and assessed cooperation to be similar, *ie*, good in 80 percent of the pts.

Pulmonary Function Tests (Table 2)

Preoperative mean values were similar for the groups, and statistical equality between the groups persisted postoperatively.

Preoperative slow vital capacity (VC) was below the reference values[16] in eight pts of the IS group and in ten pts of the IPPB group. Three of these IS pts were given IPPB or CPAP. VC in recumbent position decreased to 35 to 40 percent of the initial value on the first and second POP and recovered to 60 to 70 percent on the seventh POP. A similar course was seen in the values recorded at the sitting position, on POPs 3 to 4 and 7.

All the preoperative peak expiratory flow (PEF) results were within the normal range.[17] The nadir of PEF at 40 to 45 percent was seen on the second POP, with improvement to 70 to 80 percent on the seventh POP. The recumbent values on POPs 2 to 3 and 7 were 10 percent higher in the IPPB group than in the IS group (NS).

Five of those 11 pts that had lobar or segmental atelectasis on the sixth POP showed a pronounced decrease in VC and/or PEF on POP 2 or 3.

Observations on Chest Roentgenograms (Table 3)

Preoperatively, one IPPB pt had discoid atelectases, which persisted throughout the observation period, with concomitant low PaO_2. Postoperatively, there was intra-alveolar edema in four IS pts and one IPPB pt. Four IS and four IPBB pts exhibited interstitial pulmonary edema. In addition to these findings, which usually lasted for one to two days, 11 IS pts and nine IPPB pts showed temporary pulmonary congestion.

Slight pleural fluid, usually located left, was also a common postoperative finding; marked effusion was detected in ten IS and six IPPB pts. Four of the five IS pts with marked effusion on the third POP had segmental atelectasis at that moment, whereas none of the three similar IPPB pts did. Three IS pts showed marked effusion on the sixth POP, and in one of them, a segmental atelectasis, combined with an upward shift of the diaphragm, persisted until the sixth POP. Elevation of the diaphragm on the third POP was combined with one segmental and two subsegmental atelectases in the IS group and two segmental atelectases in the IPPB group; such a combination was observed in four IS pts (one lobar, one segmental, two subsegmental) and in two IPPB pts (segmental) on the sixth POP.

Table 3 presents the daily and cumulative (POPs 2, 3, and 6) occurrence of atelectases and their subtypes, assessed against the number of chest films taken (first six columns), as well as the number of individual patients that presented with various types of atelectases at least once in the periods of operation day-1 POP or of 2, 3, and 6 POPs (two last columns). At no stage were there any statistically significant differences between the two groups.

The chest films of those eight IS pts who had segmental or subsegmental atelectases on the operation day and/or POP 1 indicated improvement in four, deterioration in one, and a stable situation in three patients during the ensuing five days. In the corresponding four IPPB pts, the roentgenographic condition improved in two, deteriorated in one, and remained the same in one of the patients. When comparing the perioperative phase with the sixth POP, the number of patients presenting with lobar and segmental atelectases increased, as did the total number of atelectases. By the time of the sixth POP, lateral roentgenograms of seven IS and seven IPPB pts were available, and the diagnosis of atelectasis was based on them in five IS and four IPPB pts.

Table 3—*Number of Chest Films (First Six Columns) and Patients (Last Two Columns) Presenting with Atelectases after CABG**

	Oper	1 POP	2 POP	3 POP	6 POP	2,3,6 POP	Oper-1 POP	2,3,6 POP
No.	26/26	26/26	26/26	25/23	24/25	75/74	26/26	26/26
Group	IS/IPPB	IS/IPPB	IS/IPPB	IS/IPPB	IS/IPPB	IS/IPPB	IS/IPPB	IS/IPPB
Lobar	0/0	0/0	0/0	0/0	2/0	2/0	0/0	2/0
Segmental	1/1	1/0	3/2	5/3	4/5	12/10	2/1	6/5
Subsegmental	4/1	5/3	3/3	2/2	5/4	10/9	7/4	7/6
Discoid	5/8	6/7	3/5	7/6	7/4	17/15	8/12	9/8
Any kind	10/9	11/9	9/9	13/10	18/13	40/32	14/12	21/16
No kind	16/17	15/17	17/17	12/13	6/12	35/42	12/14	5/10
p values								
Various types	>0.1	>0.5	>0.7	>0.9	>0.1	>0.5	>0.5	>0.7
Any kind vs no kind	>0.7	>0.5	>0.9	>0.5	>0.05	>0.5	>0.5	>0.1

*IS = incentive spirometer; IPPB = intermittent positive pressure breathing; Oper = operation day; POP = postoperative day. As some patients had discoid atelectases combined with other types, the row "any kind" is not equal to the sum of types at that stage.

Table 4—*Inspiratory Oxygen Fraction, Arterial Blood P_{O_2} and P_{CO_2} in Patients Receiving Incentive Spirometer (IS) or Intermittent Positive Pressure Breathing (IPPB) after CABG**

				POP			
					2		
	Preoperative	After Operation	After Extubation	1 6 PM	6 AM	6 PM	3 6 AM
FI_{O_2}							
IS		0.50 ± 0.02	0.50 ± 0.01	0.48 ± 0.02	0.48 ± 0.02	0.49 ± 0.02	
IPPB		0.50 ± 0.02	0.51 ± 0.01	0.48 ± 0.01	0.49 ± 0.01	0.46 ± 0.02	
PaO_2, kPa							
IS	18 ± 1 (22)	21 ± 1 (26)	16 ± 1 (26)	14 ± 1 (26)	12 ± 0.6 (24)	12 ± 1 (20)	10 ± 1 (13)
IPPB	27 ± 2 (23)	23 ± 1 (26)	20 ± 2 (26)	15 ± 1 (26)	13 ± 1 (26)	11 ± 1 (22)	11 ± 1 (10)
$PaCO_2$, kPa							
IS	5.3 ± 0.1	5.1 ± 0.1	6.2 ± 0.2	5.8 ± 0.1	5.8 ± 0.1	5.5 ± 0.2	5.6 ± 0.2
IPPB	5.1 ± 0.1	5.4 ± 0.1	6.3 ± 0.2	5.8 ± 0.2	5.9 ± 0.2	5.4 ± 0.2	5.7 ± 0.4

*Values are mean ± SE. Number of sampling in parentheses. POP = postoperative day. For preoperative and 3 POP FI_{O_2} values, see text.

Blood Gas Values (Table 4)

The mean inspiratory concentrations of oxygen at the moment the samples were drawn were similar for the groups, beginning from the first postoperative measurement (48 to 50 percent up to the second POP, and decreasing during the third POP, when 20 pts in both groups breathed room air). The PaO_2 measured before anesthesia induction was significantly higher, and that measured soon after extubation was higher in the IPPB group than in the IS group. Otherwise, no differences between the mean values were detected. Four of the IS pts vs none of the IPPB pts had PaO_2 <9 KPa soon after extubation; thereafter, five IS and eight IPPB pts exhibited at least one sample with PaO_2 <9 KPa while breathing oxygen-enriched air. Of these 13 patients, only two had segmental, three had subsegmental, and two had discoid atelectasis simultaneously. However, three pts with normal chest films at the time of hypoxia experienced a segmental or lobar atelectasis in the next few days.

The recorded respiratory rates were similar in the two groups and the mean values of $PaCO_2$ were identical. Seventeen IS pts and 18 IPPB pts had values >6 KPa on 39 and 37 occasions, respectively.

Discussion

The value of adequate CPT and early mobilization after major surgery are well established.[3,13] Careful observation of respiration in patients subjected to cardiac surgery is mandatory, as many of them have preoperative pulmonary deficits, and the procedure effects a profound and longlasting impairment of the thoracopulmonary function.[4] The value of IS vs IPPB, as well as its benefits compared with basic CPT, following heart surgery, is controversial.[5,12-14,18] Part of the controversy may be explained by patient selection and the use of various indicators. In theory, prospective studies, using objective variables that can be measured accurately, are most reliable.[11] In the present study, patients were selected using strict criteria to make the two groups comparable. Despite that, inequality was to appear in PaO_2 before CPT was even started. Deviation in preanesthetic oxygen administration, a determinant unattended by the study participants, probably caused this disparity.

In general, no obvious differences between the study indicators and the outcome of the two groups were observed. By and large, the postoperative alterations were comparable with those detected in previous investigations.

We considered slow VC to be more precise than FVC in estimating the lung volume, as pain due to the sternal split hinders forceful expiration. The decrease in VC was of the same extent as found in two series of Gale and Sanders[12,19] (40 to 50 percent of preoperative values on first POP). In the latter study,[12] IS and IPPB pts exhibited similar alterations in VC. Stock et al[5] demonstrated even lower (30 to 40 percent) FVC on POPs 1 to 3. Vital capacity, among other lung volumes, remained depressed (66 percent) two weeks after the operation.[4] The present VC changes coincide with these observations.

The PEF, too, is affected by wound pain. It indicates respiratory muscle power and bronchial tone; the latter usually remains intact following cardiac surgery.[13] The impairment in PEF closely followed the decrement in VC. There was little intrapatient variability in the PEF recordings, and PEF should reflect the respiratory capability in a "true-to-life" situation; therefore, we found it to be a simple and suitable method for bedside surveillance after cardiac surgery.

The diminution of lung volumes provokes atelectases. Discoid atelectases are apparently unavoidable at the immediate postoperative phase.[2] In IS patients, a 69 percent incidence of atelectases was detected on the first and second POPs when exposures were taken at the upright position, including both PA and lateral projections.[19] Using these two projections the inci-

dence of atelectasis was 51 percent in IS pts compared with 53 percent in IPPB pts and a half were only discoid ones.[12] Lower incidences were seen with PA views only, 31 percent in IS and 33 percent in IPPB pts,[14] compared with 84 percent in patients with plain conventional CPT.[3] The occurrence of atelectases was highest (92 percent on the third POP), and similar in patients receiving IS or plain CPT, in the series of Stock et al.[5] However, it is impossible to compare exactly the results of these earlier studies with one another or with the present material, as the typing of atelectases differed or was not defined at all. Only Gale and Sanders[12,19] and Gale et al[2] evaluated the types of atelectases; our findings parallel their results.

We followed the roentgenographic appearance of atelectases day by day up to the third POP. It is conjectural, which of the two delineations would better represent the effect of CPT: 1 to 3+6 POP or 2 to 3+6 POP. The VC and PEF values had depressed by the first POP, but the consolidations visible on chest films apparently take at least some hours to develop. The POP 1 films were usually taken 5 to 6 h following extubation so that little time to use for CPT had elapsed between. Therefore, we consider the 2 to 3+6 POP epoch to be relevant in describing the influence of CPT.

As the occurrence of atelectases showed no statistically significant differences between the study groups, the present results support previous studies that deemed the incidence of atelectases similar, using whichever of the two devices after CABG.[5,12,14] We were disappointed to discover that the incidence of atelectases in both groups increased during the study period, that is to say that both of the methods in conjunction with CPT were unable to prevent or cure atelectases. Despite that, clinically evident pulmonary complications remained scarce, which may indicate the beneficial role of CPT in cutting the vicious circle of pulmonary impairment,[5] and also that these patients still had enough respiratory reserve to tolerate the atelectases.

The high occurrence of pleural effusions and discoid atelectases leads to their coincidental appearance.[19] Pleural fluid has[19] and has not[2] been shown to predispose to atelectasis. In the present series, persistent pleural effusions and high positioned diaphragms were complexed with subsegmental atelectases, especially in the IS group.

Incentive spirometry should open atelectatic lung compartments,[6] but a suspicion has been raised that diaphragmatic contractility might be depressed following cardiac surgery.[18] In our patients, no attempt to insulate the phrenic nerve against pericardiac cooling was instituted. This might contribute to the formation of left-sided atelectases in the IS pts who relied on active inspiration in commencing their device-oriented CPT.

Even if discoid atelectases were common, low PaO_2 levels were only incidentally detected, and, indeed, no evident linkage to atelectases was found. As alveolar-arterial oxygen gradient increases markedly after cardiopulmonary bypass,[3,4] we considered oxygen administration necessary at the moment of blood sampling during the early postoperative period. A comparison between PaO_2 in the two groups revealed no differences, in concert with two previous studies.[5,12]

Finally, two variables deserve attention in addressing the controversies on the efficiency of IS and IPPB. Adequate basic CPT and "stir-up" regimens diminish the role of mechanical devices,[13] so that no differences between IS and IPPB may be expected. Secondly, the frequency of practicing the devices should be optimized and their proper use supervised.[20] The usage rate of IS in our series (about 30 attempts/day for the first and second POPs) was probably somewhat higher than described by Iverson et al,[14] but lower than announced by Stock et al (50),[5] Dull and Dull (40),[13] and Gale and Sanders (40).[12] The use of IS is limited by patient fatigue, wound pain, and cerebral depression.[12] Obviously, patients in the weakest condition are those with the lowest usage rates. The usage rate of IPPB in the present series (about 40 inspirations/day) was less than that reported by Gale and Sanders (80)[12] and possibly less than announced by Iverson et al.[14] The number of admissions per day was, however, similar to the series mentioned above. In case of poor patient cooperation, IPPB may be administered by an assistant, but skillful assistance is needed to reach the end and to avoid gastric dilation, a risk factor for atelectasis.[2,14]

The view shared by the therapists was that young, fit patients did best with the incentive spirometer. Such patients need least help with mechanical devices. Elderly, obese, and COPD patients remain the main problem. Devices like blow bottles, CPAP, and positive expiratory pressure valves should also be compared with IS, IPPB, and each other. By mask, CPAP may be applicable following CABG,[5] and favorable results compared with IPPB and IS were achieved with blow bottles.[14] As the differences between various devices appear to be marginal, one or two of the available techniques convenient to the routines of the ward may be chosen. Assuming IS is adopted in place of IPPB, we recommend the incidence of atelectases to be followed and compared with previous figures with IPPB to ascertain the effect. If the patient cannot learn a particular method, the other one should be adopted.[20] Perhaps suspected risk patients should be instructed in the practice of two different devices, in case the other one should fail.

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