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Criteria for Weaning from Ventilator

—Predicting Weaning from Postoperative Mechanical Ventilation with Preoperative Pulmonary Function Tests—

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Abstract Predictive criteria for weaning from the postoperative mechanical ventilation using preoperative pulmonary function tests and blood gases were examined in 16 patients with impaired pulmonary function undergoing major surgery. Patients with a preoperative forced expiratory volume in one second per kg of body weight above 15 cc/kg were able to wean from the ventilator postoperatively even if they required a long period for mechanical ventilatory support. Therefore, the preoperative forced expiratory volume in one second per kg of body weight can be a useful index for predicting the possibility of weaning from the ventilator in surgical patients with the disturbed pulmonary function when they need mechanical ventilation postoperatively.

Key Words : Lung : pulmonary function test, Ventilaition : mechanical, weaning, Complications : postoperative respiratory failure

Introduction

Recent advances in operative techniques and perioperative patient management have permitted wider latitude in patients selection for surgery and have thereby accentuated the importance of careful and accurate preoperative evaluation. Pulmonary complications are the most common cause of morbidity and mortality after major surgical procedures, and chronic pulmonary disease is the most important single factor leading to postoperative pulmonary complications[1]. Williams and Brenowitz[2] have stated that patients should not be denied necessary operative procedures solely on the basis of pulmonary function tests (PFTs) which place them in the "prohibitive" range of Miller's quadrant diagram[3]. Although techniques for the preoperative assessment of respiratory function that predict the requirement for postsurgical ventilation have been published[3)-6)], studies which predicted the possibility for weaning from the postoperative mechanical ventilation using the preoperative PFTs and blood gas values can not be found. The anesthesiologist must be able to anticipate preoperatively the likelyhood of the patient weaning from the postoperative ventilatory support when once surgical patient was placed on ventilator.

This study was designed to establish prediction for weaning from the postoperative mechanical ventilation using the preoperative PFTs and blood gases in patients with disturbed pulmonary function undergoing major

surgery.

Method

Sixteen surgical patients whose preoperative PFT data would correspond to the "prohibitive" range of the quadrant diagram introduced by Miller and colleagues[3] were divided into three groups and were studied retrospectively. Table 1, 2, and 3 list the operations performed, operating time, anesthetics used, and outcomes in the 16 patients. Diagnosis was made according to diagnostic criteria[7]. They were all schedulled for elective surgery except case 6, who received an emergency operation due to massive gastrointestinal hemorrhage during his stay in the internal medicine ward. His PFT was obtained before the hemorrhagic insult.

Preoperative PFTs in the sitting position were performed by technicians in the respiratory laboratory using a spirometer Chest 35 (Chest Corporation, Tokyo). The forced vital capacity (FVC), forced expiratory volume in one second ($FEV_{1.0}$) and vital capacity (VC) were measured. The percent vital capacity (%VC) was expressed as a percent of the predicted VC and percent forced expiratory volume in one second ($\%FEV_{1.0}$) was

Table 1 Operations performed, anesthetics used, and outcome in 6 patients requiring prolonged artificial ventilation during the postoperative period (group 1).

No.	Age yrs	Sex	BW kg	Diagnosis	Operation (time,min)	Anes-thetics	Venti-lation(days)	Outcome
1	73	F	43	Gastric cancer Broncheal asthma	Partial gastrectomy (175)	GOH	37	Survived
2	67	M	40	Gastric cancer Emphysema	Partial gastrectomy (165)	GOH	24	Survived
3	73	M	56	Hepatoma Emphysema	Segmental hepatectomy (136)	NLA	64	Died
4	69	F	43	Gastric cancer Broncheal asthma	Gastrojejunostomy (100)	GOH	25	Died
5	72	M	41	Gastric cancer Chronic bronchitis	Total gastrectomy (320)	GOH	45	Died
6	58	M	55	Gastric cancer Broncheal asthma	Partial gastrectomy (150)	GOH	62	Died

Abbreviations : F, female ; M, male ; yrs, years.

Table 2 Operations performed, anesthetics used, and outcome in 7 patients not requiring prolonged artificial ventilation during the postoperative period (group 2).

No.	Age yrs	Sex	BW kg	Diagnosis	Operation (time,min)	Anesthetics	Outcome
7	49	F	39	Breast cancer	Right mastectomy (180)	GOH	Survived
8	79	F	40	Left renal cancer Emphysema	Left nephroureterectomy (170)	NLA	Survived
9	56	F	48	Breast cancer Old Pulmonary tbc	Right mastectomy (150)	GOE	Survived
10	71	M	54	Gastric cancer Emphysema	Partial gastrectomy (140)	GOE	Survived
11	69	M	43	Choledocholithiasis Emphysema	Choledochojejunostomy (210)	GOE	Survived
12	66	M	41	Sigmoid cancer Emphysema	Sigmoidectomy (160)	GOE	Survived
13	65	M	47	Gastric cancer Chronic bronchitis	Partial gastrectomy (270)	fentanyl diazepam enflurane	Survived

Abbreviation : tbc, tuberculosis

Table 3 Operations performed, anesthetics used, and outcome in 3 patients with restrictive pulmonary disease not requiring prolonged postoperative artificial ventilation (group 3).

No.	Age yrs	Sex	BW kg	Diagnosis	Operation (time,min)	Anesthetics	Outcome
14	64	F	30	Sigmoid cancer Old pulmonary tbc	Sigmoidectomy (155)	GOE	Survived
15	58	F	33	Bladder tumor Right hydronephrosis Old pulmonary tbc	Partial cystectomy Ureteronephrectomy (180)	GOE	Survived
16	80	M	32	Gastric cancer Mitral valve stenosis Tricuspid valve regurgitation	Partial gastrectomy (130)	GOE	Survived

expressed as a percentage of the FVC. The values of VC and $FEV_{1.0}$ were divided by the body weight (BW) and expressed by cc/kg. Arterial blood gases were obtained while the patient was breathing room air before anesthesia induced, except case 10, whose blood gas value was on 30% oxygen. Arterial oxygen tension (PaO_2), arterial carbon dioxide tension ($PaCO_2$), and pH were measured with a blood gas analyzer (178 pH/Blood Gas Analyzer, Corning, MA).

General anesthesia was induced with halothane or enflurane, pancuronium bromide (PBr) was used as a muscle relaxant for endo-tracheal intubation, and anesthesia was maintained with 50-67% nitrous oxide in oxygen, supplemented with either halothane (GOH), enflurane (GOE) or fentanyl and droperidol (NLA). The PBr was added for muscle relaxation as needed. All patients were admitted to ICU overnight for observation after surgery and were mechanically ventilated because their preoperataive PFT data were placed in the "prohibitive" range of Miller's quadrant diagram. The 16 patients were divided into 3 groups on the basis of the period of post-operative mechanical ventilation and the findings of the preoperative PFTs. Group 1 consisted of 6 patients whose results of PFTs showed obstructive pulmonary disease. They were ventilated mechanically from 24 to 62 days after surgery. Two of them (case 1 and 2) were successfully weaned from the ventilator at 37 and 24 postoperative days, respectively, after many attempts to wean them ; two of others (case 3 and 5) failed at all attempts to wean, and for the remaining patients no attempts to wean were possible because of their failure to maintain an adequate cardiopulmoanry status with spontaneous breathing. All patients received controlled mechanical ventilation to maintain their PaO_2 above 80 mmHg at an inspired oxygen fraction (F_IO_2) of 0.5, occasionally, with positive end-expiratory pressure (less than 4 cm of H_2O) as needed until instituting weaning. Weaning was initiated when, with intermittent mandatory ventilation, the patients had a PaO_2 above 80 mmHg on F_IO_2 of less than 0.5, alert consciousness, and adequate cardiopulmonary status. The ventilator was discontinued when the patients needed less than 4 positive pressure breaths per min. Groups 2 and 3 consisted of 7 patients and 3 patients, respectively, and their results of PFTs were obstructive pulmonary disease and restrictive pulmonary disease, respectively. All of them were extubated after a few hours of postoperative mechanical ventilation in the ICU. Weaning in groups 2 and 3 was accomplished in the same manner as it was for group 1. All values are expressed as the mean $\pm$S. D. Differences in the values of the PFTs and blood gas analyses were tested between three groups using the Kruskal-Wallis statistic for unpaired comparison. Probability values of less than < 0.05 were considered to be of statistical significance.

Results

The results of the PFTs and blood gas analyses for groups 1, 2, and 3 are listed in tables 4, 5, and 6, respectively. Significant differences were observed in $FEV_{1.0}$ and $FEV_{1.0}$/BW between group 1 and group 2, and in VC, %VC, $FEV_{1.0}$/BW, and $\%FEV_{1.0}$ between group 1 and group 3. It is expected to observe significantly lower VC, %VC and large $FEV_{1.0}$ in patients group 3 because they were the restrictive pulmonary disease. There were no significant differece in $FEV_{1.0}$

Table 5 Results of pulmonary function tests and blood gas analyses in patients not requiring prolonged artificial ventilation during the postoperative period (group 2).

No.	VC cc	VC/BW cc/kg	%VC %	$FEV_{1.0}$ cc	$FEV_{1.0}$/BW cc/kg	$\%FEV_{1.0}$ %	PaO_2 mmHg	$PaCO_2$ mmHg	pH	B.E. mEq/l
7	1920	49	72	650	17	34	88	39	7.40	0
8	1790	45	92	850	21	52	86	42	7.41	2
9	2050	43	84	700	15	35	62	43	7.38	0
10	3540	66	108	970	18	31	106*	36	7.47	3
11	2100	49	69	980	23	47	54	46	7.46	7
12	3800	93	116	760	19	20	72	36	7.42	0
13	2600	57	83	770	16	29	74	47	7.37	0
mean	2543	57	89	811**	17**	35	73	42	7.42	2
S.D.	814	18	18	128	3	11	13	4	0.04	3

*, $F_IO_2=0.3$, excluded from statistical analysis. **, $p<0.05$ compared to group 1.

Table 6 Results of pulmonary function tests and blood gas analyses in patients with restrictive pulmonary disease not requiring prolonged postoperative artificial ventilation (group 3).

No.	VC cc	VC/BW cc/kg	%VC %	$FEV_{1.0}$ cc	$FEV_{1.0}$/BW cc/kg	$\%FEV_{1.0}$ %	PaO_2 mmHg	$PaCO_2$ mmHg	pH	B.E. mEq/l
14	690	23	29	480	16	73	67	58	7.40	8
15	1260	38	54	740	22	59	86	33	7.44	1
16	1020	32	52	560	18	68	77	43	7.46	6
mean	990*	31	45*	593	19*	67*	77	45	7.43	5
S.D.	286	8	14	133	3	7	10	13	0.03	4

*, $p<0.05$ compared to those of group 1.

Table 4 Results of pulmonary function tests and blood gas analyses in patients requiring prolonged artificial ventilation during the postoperative period (group 1).

No.	VC cc	VC/BW cc/kg	%VC %	$FEV_{1.0}$ cc	$FEV_{1.0}$/BW cc/kg	$\%FEV_{1.0}$ %	PaO_2 mmHg	$PaCO_2$ mmHg	pH	B.E. mEq/l
1	1400	33	71	650	15	45	58	48	7.42	6
2	2100	53	70	580	15	28	69	38	7.43	2
3	3070	55	116	640	12	23	70	37	7.44	1
4	1590	37	75	460	11	31	58	38	7.49	5
5	1890	46	62	550	13	30	55	52	7.45	6
6	2110	38	62	500	9	25	58	38	7.45	5
mean	2027	44	76	563	13	30	61	42	7.41	4
S.D.	584	9	20	76	2	8	6	6	0.09	2

Abbreviation ; B. E., base excess

between survived patients (group 3) and non-survived patients (group 1). The values of $FEV_{1.0}$/BW in groups 2 and 3 were significantly higher than those of group 1. All the patients in groups 2 and 3 and the two patients in group 1, who were successfully weaned from ventilator at 37 and 24 postoperative days had $FEV_{1.0}$/BW values of 15-23cc/

kg. However, the patients in group 1, who died on the ventilator, had $FEV_{1.0}$/BW values of less than 15 cc/kg (they ranged from 13 to 9 cc/kg). The 95 percent confidence limits of $FEV_{1.0}$/kg ranged between 11.4 and 14.6 in patients in group 1, and in groups 2 and 3 their 95 percent confidence limits ranged between 14.8 and 19.2, 15.6 and 22.4, respectively. No significant differences were observed in blood gas values between groups 1, 2, and 3. A PaO_2 of case 10 was excluded from statistical analysis because his inspired oxygen was thirty percent. Four patients in group 1 died from respiratory problems : acute pneumonia (P. aeruginosa) complicating serious other disease including hepatorenal failure (case 3 and 5), sepsis (case 4), and advanced malignacy associated with multiple metastasis on autopsy including the lung (case 6). The three patient groups did not differ significantly with respect to operating time, age, and body weight.

Discussion

The many recent advances in perioperative care and medical equipment, including monitors and artificial ventilators have made it possible to operate successfully on patients previously considered at inordenately high risk. Williams and Brenowitz[2] found that sixteen patients whose preoperative PFT data were placed in the "prohibitive" range of Miller's quadrant diagram[3] underwent major surgical procedures with one death (6 percent mortality) and three cases of major pulmonary complications (19 percent).

They subsequently proposed that the term "prohibitive" should be changed to "increased risk" and that these patients should not forgo necessary surgery ; rather, that postoperative problems should be expected and all efforts made to obviate them. Milledge and Nunn[5] used the preoperative PFTs and blood gas analyses to assess pulmonary function in 15 patients with COPD, and clearly demonstrated the preoperative criteria for postoperative mechanical ventilation. They found that the $FEV_{1.0}$ is a good preoperative assessment of postoperative respiratory support requirements, but it should be supplemented by arterial blood gases in patients with an $FEV_{1.0}$ of less than 1 litre. Gracey and colleagues[6] reported that the single most reliable test for predicting the necessity of postoperative mechanical ventilation was mean forced expiratory flow taking during the middle of the FVC measurement. Although these studies have made it possible to predict the need for postoperative mechanical respiratory support, the question of preoperative prediction of which patients can be successfully weaned from the ventilation was not addressed. Schwaber[8] reported that patients with less than 1 litre VC or less than 500 cc $FEV_{1.0}$ should not have surgery expect for life-threatening condition ; but in Williams and Brenowitz's series, three patients in this category were operated on and only one of them had a respiratory complications.

In our series, of three patients who fell in the category defined by Schwaber, two died. However, the other two patients who died on the ventilator had a VC above 1 litre and an $FEV_{1.0}$ above 500 cc. Although the absolute values of the PFTs and blood gas analyses may be valuable in evaluating the requirement for postoperative ventilatory support, these values will not provide the information needed to predict the possible difficulty of weaning them from ventilator once they have placed on it.

In this study, both of $FEV_{1.0}$ and $FEV_{1.0}$/BW differed significantly between the patients required prolonged postoperative ventilatory support (group 1) and the patients not requiring prolonged ventilatory support (group 2). But $FEV_{1.0}$ will not be able to be used as criteria for weaning because two of three patients in group 3, not requiring prolonged postoperative ventilatory support, showed smaller $FEV_{1.0}$ (480, 560 cc) compared with those in group 1. When we expressed the PFT values per kg of body weight, an $FEV_{1.0}$/BW above 15 cc/kg was observed in all patients in groups 2 and 3, and the two patients in group 1 who were able to be wean from the ventilator in spite of prolonged postoperative mechanical ventilation. The upper value of the 95 percent confidence limits of $FEV_{1.0}$/BW was about 15 cc/kg in patients in group 1, and in patients in group 2,

lower value of it was about 15 cc/kg. This suggests that an $FEV_{1.0}$/BW of 15 cc/kg may be a critical value for predicting the possibility of weaning from the mechanical ventilator in the postoperative period. When the $FEV_{1.0}$/BW is at least 15 cc/kg, the patients will be able to be weaned from the ventilator even if prolonged mechanical vetilation is necessary in the postoperative period. With modern anesthesiology, the provision of ventilatory assistance or control during operative procedures rarely presents an unmanageable problem. However, anticipation of the need for postoperative mechanical ventilation and the possibility of weaning the patients from the ventilator are necessary if serious pulmonary complications are to be avoided. Three patients, except case 6 who had advanced malignancy, died from respiratory failure or related complications with 25 to 64 days after operation although vigorous respiratory therapy including tracheal suctioning, forced coughing and deep breathing, and chest percussion was applied during their stay in ICU. Operations in the upper abdomen in patients with an $FEV_{1.0}$/BW of less than 15 cc/kg could increase the incidence of life-threatening pulmonary complications during the postoperative period.

In conclusion, the preoperative values of the $FEV_{1.0}$/BW can be a useful index for predicting the postoperative requirement for ventilatory assisstance and the possibility of weaning from the ventilator. Patients with a preoperative $FEV_{1.0}$/BW above 15 cc/kg will likely be weanable from the ventilator postoperatively even if they require a long period of mechanical ventilatory support.

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