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Cardiorespiratory dynamics during successful and unsuccessful trials of weaning from mechanical ventilation following cardiac surgery

YOSHINORI NISHIYAMA and MASAHARU ITO

Department of Anesthesia, Ehime Rosai Hospital, 13–27 Minamikomatsubara, Niihama, Ehime, 792 Japan

Abstract: The purpose of this study was to examine the effects of a weaning trial with pressure support ventilation (PSV) on the cardiorespiratory dynamics in 20 cardiac surgery patients. In the patients who failed a weaning trial (failure group, $n = 6$), the mean duration of cardiopulmonary bypass was 270 ± 83 min and the mean postoperative lung-thorax compliance was 38 ± 5 ml·cmH_2O^{-1}, whereas in successfully weaned patients (success group, $n = 14$) they were 145 ± 30 min and 55 ± 10 ml·cm H_2O^{-1} respectively (mean ± SD). Significant differences were recognized in those values between the two groups. Preoperative cardiac function, intraoperative blood loss, and postoperative fluid balance were similar in both groups. Cardiac index (CI) increased similarly in both groups. Pa_{O_2}/FI_{O_2} and percentage intrapulmonary shunt were constant in the success group, and these variables worsened in the failure group. Oxygen consumption ($\dot{V}O_2$) increased and mixed venous O_2 tension ($P\bar{v}O_2$) decreased in the failure group, whereas $\dot{V}O_2$ remained constant and $P\bar{v}O_2$ increased in the success group. These data suggest that prolonged cardiopulmonary bypass might have produced acute lung injury. Decreased lung compliance may be responsible for rapid shallow breathing and an increase in oxygen consumption during a weaning trial, and may lead to weaning failure from mechanical ventilation.

Key words: Cardiorespiratory dynamics—Breathing pattern—Weaning from mechanical ventilation—Cardiac surgery patient

Introduction

Mechanical ventilation is obviously a life-saving measure in many diseased conditions. However, it is sometimes associated with serious complications. Therefore it is preferable to discontinue it as soon as possible. Nevertheless, it is not uncommon for patients to fail a weaning trial from mechanical ventilation. The causes of failed weaning are reported to be complicated [1]. In one report, decreased cardiac index (CI) and oxygen supply were considered to be the reason for weaning failure [2], whereas in another report CI and oxygen supply were increased during a weaning period in both successfully and unsuccessfully weaned patients who had undergone cardiac surgery [3]. To better understand the cause of weaning failure, we examined the cardiorespiratory dynamics during a weaning trial with pressure support ventilation in cardiac surgery patients.

Materials and methods

Twenty patients who underwent elective coronary artery bypass surgery were studied. Patients who had preexisting pulmonary disease were excluded. All patients were intubated with an endotracheal tube with an inner diameter of 7.5–8.5 mm and anesthetized with high-dose fentanyl, oxygen and pancuronium. To monitor cardiovascular function, a Swan-Ganz catheter was placed in the right jugular vein, and the radial artery was cannulated. Preoperative autologous blood donation and intraoperative blood salvage were done, and if transfusion was necessary, autologous blood was infused.

Cardiopulmonary bypass (CPB) was initiated with a membrane oxygenator with pulsatile perfusion using Sarns roller pumps (Sarns, Ann Arbor, MI, USA). During CPB, the activated coagulation time was maintained above 400 s by intravenous injection of heparin. When full flow was achieved, hypothermia was induced, and cardiac arrest was produced by infusion of St. Thomas's cardioplegic solution. Mechanical ventilation of the lungs was then discontinued. After total bypass, rewarming was commenced and cardiac rhythm was

Address correspondence to: Y. Nishiyama
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restored by counter shock to the heart. Mechanical ventilation was recommenced, and the patients were weaned from bypass.

Following surgery, mechanical ventilation was delivered in a controlled mode using a Veolar ventilator (Hamilton Medical, Rhäzüns, Switzerland) with the following settings: tidal volume 10–12 ml/kg, inspiration/expiration ratio 1:2, square wave, level of positive end-expiratory pressure (PEEP) 5 cmH_2O or less, and respiratory rate sufficient to maintain normocarbia. Before the start of weaning from mechanical ventilation, lung-thorax compliance was estimated as expiratory tidal volume/(pause pressure—end expiratory pressure).

Within 48 h after the end of operation, weaning was started when the patients met all of the following conditions: stable hemodynamics, conscious and cooperative, maximal inspiratory force exceeding -20 cmH_2O, $Pao_2 \geqq 100$ mmHg with FIo_2 of 0.5 or less, $Paco_2 \leqq 45$ mmHg, and blood pH > 7.30.

At the start of weaning, patients were placed on pressure support ventilation (PSV) with the trigger sensitivity set at -2 cmH_2O. The process of weaning consisted of the following three stages. The first stage was PSV 10 cmH_2O; the second, PSV 5 cmH_2O; and the third, PSV 0 cmH_2O (continuous positive airway pressure, CPAP). Each level was maintained for 20 min and measurements were taken in the last 5 min of each period, and then they were extubated. Weaning was abondoned when they met one of the following criteria: evidence of increasing respiratory effort and dyspnea, arrhythmias, heart rate > 130 bpm, blood pressure decrease >15 mmHg, $Pao_2 < 80$ mmHg with Fio_2 0.5, $Paco_2 \geqq 50$ mmHg, and blood pH $\leqq 7.30$. During the study period, the level of PEEP was kept constant.

All 20 patients could be weaned to PSV 5 cmH_2O, but in 4 patients weaning was stopped at CPAP because they met criteria mentioned above. The other 16 patients were extubated, but 2 patients needed reintubation due to respiratory complications.

Weaning from mechanical ventilation was considered successful when the patient could be extubated and did not need reintubation for respiratory reasons within 24 h after extubation.

The following variables were measured: (1) hemodynamic variables: heart rate (HR), mean arterial pressure (MAP), mean pulmonary arterial pressure (MPAP), pulmonary capillary wedge pressure (PCWP), cardiac index (CI), and left ventricular stroke work index (LVSWI); (2) gas exchange variables: percentage intrapulmonary shunt ($\dot{Q}_S/\dot{Q}_T$), Pao_2/FIo_2, $Paco_2$, mixed venous O_2 tension ($P\bar{v}O_2$), and oxygen consumption; and (3) variables of breathing pattern: tidal volume (VT), minute volume (MV), respiratory rate (f), airway occlusion pressure at 0.1 s ($P_{0.1}$), duty cycle (T_I/T_{tot}), and mean inspiratory flow (VT/T_I).

Blood gas analysis was done using a blood gas analyzer (Model 278, CIBA-Corning, Medfield, MA, USA). Arterial and pulmonary artery oxygen content were determined with a co-oximeter (Model 2500, CIBA-Corning). Cardiac output was estimated by the thermodilution technique and oxygen consumption was calculated using Fick's principle. Other hemodynamic and gas exchange parameters were calculated using standard formulas.

Inspiratory and expiratory flow and tidal volume were measured with a calibrated variable orifice flow sensor which was placed between the proximal end of the endotracheal tube and the Y-piece of the ventilator. The airway pressure was measured with the in-line pressure transducer of the ventilator. The flow, airway pressure and volume signals were displayed and recorded with a bedside monitoring device (Leonardo, Hamilton Medical). From the flow signal, the respiratory rate, inspiratory time (T_I) and total respiratory duration (T_{tot}) were measured, and T_I/T_{tot} and VT/T_I were calculated [4]. The value of $P_{0.1}$ was estimated using the inspiratory effort against the closed demand value [5].

All data are presented as mean ± SD. Statistical analysis was done by Wilcoxon's signed-rank test or the Mann-Whitney U-test. Probability values < 0.05 were considered significant.

Results

The patients were divided into the success group ($n = 14$) and failure group ($n = 6$). The age, sex, height, and weight of the patients was 68 ± 6 years (eight men and six women), 157 ± 7 cm, and 59 ± 8 kg in the success group; 67 ± 5 years (three men and three women), 150 ± 3 cm, and 54 ± 9 kg in the failure group respectively, and there was no significant difference between the two groups in terms of age, sex, height, and weight of the patients.

The perioperative conditions of the patients are summarized in Table 1. In the success group, duration of CPB was shorter, and postoperative lung-thorax compliance was larger than that in the failure group. There were no significant differences between the two groups in preoperative LVEF, number of bypass grafts per patient, intraoperative blood loss, and PEEP level during weaning. All 20 patients were not complicated with shock or with serious liver or renal dysfunction during the perioperative period. Postoperative fluid balance was similar between both groups.

The hemodynamic data are summarized in Table 2. HR and MPAP remained constant during weaning, but the values were higher in the failure group. MAP, PCWP, and LVSWI did not change during weaning. As the level of pressure support decreased from 10 to

Table 1. Perioperative conditions of the patients

	Success (n = 14)	Failure (n = 6)
Preoperative LVEF (%)	56 ± 14	50 ± 10
Number of bypass grafts	2.3 ± 0.7	2.5 ± 0.8
Duration of CPB (min)	145 ± 30*	270 ± 83
Intraoperative blood loss (g)	869 ± 368	1181 ± 610
C_{LT} before weaning trial ($ml \cdot cmH_2O^{-1}$)	55 ± 10*	38 ± 5
PEEP level during weaning (cmH_2O)	3 ± 2	4 ± 1

Values are mean ± SD.
* $P < 0.05$ as compared with failure group.
LVEF, left ventricular ejection fraction; CPB, cardiopulmonary bypass; C_{LT}, lung-thorax compliance; PEEP, positive end-expiratory pressure.

Table 2. Hemodynamic parameters during weaning

	PSV10cmH_2O	PSV5cmH_2O	CPAP
HR ($beats \cdot min^{-1}$)			
Success	87 ± 10	87 ± 12	87 ± 11
Failure	104 ± 15#	104 ± 15#	107 ± 22#
MAP (mmHg)			
Success	83 ± 14	88 ± 14	86 ± 13
Failure	94 ± 21	96 ± 23	103 ± 25
MPAP (mmHg)			
Success	20 ± 4	20 ± 3	19 ± 3
Failure	23 ± 6	26 ± 3#	25 ± 4#
PCWP (mmHg)			
Success	12 ± 4	12 ± 4	12 ± 3
Failure	15 ± 3	14 ± 3	13 ± 3
CI ($l \cdot min^{-1} \cdot m^{-2}$)			
Success	2.8 ± 0.7	2.8 ± 0.6	3.0 ± 0.8*
Failure	2.7 ± 0.5	2.8 ± 0.4	3.0 ± 0.6*
LVSWI ($kg \cdot m \cdot m^{-2}$)			
Success	2.8 ± 1.2	3.1 ± 1.2	3.0 ± 1.1
Failure	3.0 ± 1.3	3.3 ± 1.2	3.5 ± 1.8

Values are mean ± SD.
* $P < 0.05$ *vs.* PSV10.
# $P < 0.05$ *vs.* success group.
PSV, pressure support ventilation; CPAP, continuous positive airway pressure; HR, heart rate; MAP, mean arterial pressure; MPAP, mean pulmonary artery pressure; PCWP, pulmonary capillary wedge pressure; CI, cardiac index; LVSWI, left ventricular stroke work index.

0 cmH_2O, CI increased in both groups. No significant difference was recognized between the two groups in these variables.

Table 3 contains gas exchange data. Pao_2/FIo_2 and $\dot{Q}_S/\dot{Q}_T$ were constant during weaning in the success group, but these variables worsened in the failure group as the patients were weaned from PSV 10 cmH_2O to CPAP. At CPAP, Pao_2/FIO_2 was higher and $\dot{Q}_S/\dot{Q}_T$ was lower in the success group than in the failure group. During weaning, $\dot{V}O_2$ increased and $P\bar{v}O_2$ decreased in the failure group, whereas $\dot{V}O_2$ remained constant and $P\bar{v}O_2$ increased in the success group.

The data of breathing patterns is given in Table 4. $P_{0.1}$ and f/VT increased as the patients were weaned in both groups, but the values were higher in the failure group at each level of pressure support. MV was unchanged, T_I/T_{tot} increased, and VT/T_I decreased during weaning in both groups. No significant difference was recognized between the two groups in these variables.

Two of the six patients in the failure group were complicated with bronchial pneumonia, and required prolonged ventilatory support for more than 20 days. In the other four patients, respiratory failure gradually improved, and they were weaned from mechanical ventilation within 14 days after the initial trial of weaning.

Discussion

In the present study of postoperative patients who underwent aortocoronary bypass surgery, VT/T_I, an index of respiratory center output, and T_I/T_{tot}, an index of respiratory muscle function, were not different between the groups. Therefore, decreased respiratory center

Table 3. Gas exchange parameters during weaning

	PSV10cmH_2O	PSV5cmH_2O	CPAP
Pao_2/FIo_2			
Success	2.8 ± 0.6	2.8 ± 0.6	2.7 ± 0.7
Failure	2.6 ± 0.3	2.5 ± 0.3	2.1 ± 0.4*#
$\dot{Q}_S/\dot{Q}_T$(%)			
Success	11 ± 3	11 ± 3	12 ± 3
Failure	12 ± 1	13 ± 3	15 ± 3*#
$PaCO_2$ (mmHg)			
Success	33 ± 7	37 ± 5	38 ± 4*
Failure	33 ± 4	37 ± 2	36 ± 1
$P\bar{v}O_2$ (mmHg)			
Success	33 ± 5	35 ± 4	35 ± 4*
Failure	31 ± 3	31 ± 2#	30 ± 2*#
$\dot{V}O_2$ ($ml \cdot min^{-1} \cdot m^{-2}$)			
Success	146 ± 28	151 ± 32	150 ± 29
Failure	141 ± 25	151 ± 30*	162 ± 33*

Values are mean ± SD.
* $P < 0.05$ *vs*. PSV10cmH_2O.
# $P < 0.05$ *vs*. success group.
$\dot{Q}_S/\dot{Q}_T$, percentage intrapulmonary shunt; $P\bar{v}O_2$ mixed venous O_2 tension; $\dot{V}O_2$, oxygen consumption.

Table 4. Parameters of breathing pattern during weaning

	PSV10cmH_2O	PSV5cmH_2O	CPAP
MV ($l \cdot min^{-1}$)			
Success	7.6 ± 2.8	6.7 ± 1.6	6.5 ± 1.6
Failure	10.4 ± 4.2	9.9 ± 2.8	8.9 ± 3.3
f/VT ($breaths \cdot min^{-1} \cdot l^{-1}$)			
Success	29 ± 13	31 ± 9	39 ± 14*
Failure	44 ± 17#	64 ± 30*#	66 ± 28*#
$P_{0.1}$ (cmH_2O)			
Success	2.2 ± 1.5	3.0 ± 1.9	3.4 ± 1.8*
Failure	4.9 ± 2.4#	5.7 ± 1.8#	6.0 ± 1.5*#
T_I/T_{tot}			
Success	0.37 ± 0.15	0.42 ± 0.13*	0.49 ± 0.18*
Failure	0.33 ± 0.10	0.38 ± 0.07	0.42 ± 0.07*
VT/T_I ($ml \cdot sec^{-1}$)			
Success	450 ± 80	370 ± 60*	330 ± 50*
Failure	510 ± 160	430 ± 70*	340 ± 90*

Values are mean ± SD.
* $P < 0.05$ *vs*. PSV10cmH_2O.
# $P < 0.05$ *vs*. success group.
MV, minute volume; f, respiratory rate; VT, tidal volume; $P_{0.1}$, airway occulsion pressure at 0.1 sec; T_I, inspiratory time; T_{tot}, total respiratory duration.

output or abnormal respiratory muscle function was not considered to be the cause of weaning failure. Likewise, weaning failure obviously could not be attributed to cardiac dysfunction because there was no difference between the two groups in CI, LVSWI, and PCWP.

All 20 patients had no preexistent pulmonary disease before surgery, and were not complicated with shock, serious liver or renal dysfunction, or extremely positive fluid balance; however, postoperative lung-thorax compliance was lower in the failure group. This suggests that acute lung injury due to some other reason had occurred during the perioperative period.

In the failure group, the mean bypass time was 270 min, which was almost twice as long as that in the success group. Prolonged cardiopulmonary bypass more than 3 h has been known to produce acute lung injury [6]. Braude et al. [7] reported that endothelial cells were damaged and permeability of pulmonary vasculture was increased in such conditions. Ratliff et al. [8] studied ultrastructural change in lung biopsies obtained from patients before and after CPB, and described that alterations following CPB were similar to those reported following various forms of shock and trauma. Swelling of endothelial cells, alveolar and interstitial edema, engorgement of the pulmonary vascular bed, and development of miliary atelectasis were reported to be features of lung injury after CPB [8]. We consider that such deleterious changes probably contributed to the lower values of lung-thorax compliance observed in the failure group.

Rapid shallow breathing (higher f/VT ratio) and increased respiratory drive (higher $P_{0.1}$ value) were seen in the failure group. We suspect that a decrease in lung-thorax compliance was responsible for the observed breathing pattern in the failure group. Under such conditions, respiratory work and oxygen consumption were reportedly increased [9]. Therefore, $P\bar{v}O_2$ decreased in spite of an increase in CI during a weaning trial.

In conclusion, prolonged cardiopulmonary bypass produced possible acute lung injury. Decreased lung compliance seems to cause rapid shallow breathing and an increase in oxygen consumption during weaning trials, and is considered to be the cause of failed weaning from mechanical ventilation.

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References

1. Tobin MJ (1990) Weaning from mechanical ventilation. Curr Pulmonol 11:47–105
2. Wolff G, Gradel E (1975) Haemodynamic performance and weaning from mechanical ventilation following open-heart surgery. Eur J Intens Care Med 1:99–104
3. Kennedy SK, Weintraub RM, Skillman JJ (1977) Cardiorespiratory and sympathoadrenal responses during weaning from controlled ventilation. Surgery 82:233–240
4. Tobin MJ (1992) Breathing pattern analysis. Intens Care Med 18:193–201
5. Fernandez R, Benito S, Sanchis J, et al. (1988) Inspiratory effort and occulusion pressure in triggered mechanical ventilation. Intens Care Med 14:650–653
6. Asada S, Yamaguchi M (1971) Fine structural change in the lung following cardiopulmonary bypass. Chest 59:478–483
7. Braude S, Nolop KB, Fleming JS, et al. (1986) Increased pulmonary transvascular protein flux after canine cardiopulmonary bypass. Am Rev Respir Dis 134:867–872
8. Ratliff NB, Young WG, Hackel DB, et al. (1973) Pulmonary injury secondary to extracorporeal circulation. An ultrastructural study. J Thorac Cardiovasc Surg 3:425–432
9. Tobin MJ, Perez W, Guenther SM, et al. (1986) The pattern of breathing during successful and unsuccessful trials of weaning from mechanical ventilation. Am Rev Respir Dis 134:1111–1118