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Changes in respiratory pattern during continuous positive airway pressure in infants after cardiac surgery

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Abstract
Purpose. Spontaneous breathing trials are commonly used in adults to enable smooth weaning from mechanical ventilation. However, few investigations have examined spontaneous breathing tests in infants. We investigated how respiratory patterns of infants changed during continuous positive airway pressure (CPAP) and whether successful extubation followed CPAP.
Methods. Fifty-one consecutive post—cardiac surgery infants satisfied the following weaning criteria: stable hemodynamics, pH > 7.30, tidal volume > 5 ml·kg^{-1}, and respiratory rate < 50 breaths·min^{-1} with pressure control of 10–16 cm H_2O. We applied CPAP of 3 cm H_2O for 30 min to these 51 infants. During CPAP, tidal volume, respiratory rate, and arterial blood gases were measured. CPAP was terminated if the patient showed a sustained increase or decrease in heart rate or blood pressure (>20%), a decrease in arterial oxygen saturation (>5%), agitation, or diaphoresis. After the completion of CPAP, tracheal extubation was performed. We considered extubation successful if no reintubation was required in the ensuing 48 h.
Results. Although hemodynamic and ventilatory variables were unstable for the first 5 min, they stabilized after 10 min of CPAP. Fifty infants completed the CPAP trial safely. Of these, 46 (92%) underwent successful extubation after the CPAP trial. The failure group (4 infants) showed lower pH, higher arterial carbon dioxide tension, and more rapid shallow breathing during CPAP than the success group.
Conclusion. After cardiac surgery, when infants recovered stable hemodynamics and spontaneous breathing, the ventilatory pattern and hemodynamics became stable after 10 min of CPAP. Ninety-two percent of the patients were successfully extubated following a 30-min CPAP trial.

Key words Continuous positive airway pressure · Extubation · Cardiac surgery · Infant

Introduction

To achieve successful weaning from mechanical ventilation for adults, spontaneous breathing tests are commonly applied [1,2]. For ventilator-dependent adult patients, 2-h T-piece trials enabled earlier extubation, compared with synchronized intermittent mandatory ventilation and pressure support ventilation [3]. In a follow-up study, 30-min T-piece trials were as effective as 2-h trials [4]. For infants, however, few investigations have examined whether a spontaneous breathing test, in the current study a continuous positive airway pressure (CPAP) trial, provides smooth weaning [5,6].

The most commonly used ventilatory modes for infants are intermittent mandatory ventilation or assist control ventilation, both of which are combined with pressure control ventilation. Because the work of breathing changes in proportion to the mandatory breath rate [7] or pressure control level [8], weaning usually involves a gradual decrease in the number of mandatory breaths or level of pressure control [1]. Understanding that spontaneous breath trials using the T-piece work well for adults, we carried out a prospective observational study to investigate how the infant respiratory pattern changes during 30 min of CPAP. We then investigated whether tolerance of the CPAP trial was related to successful extubation.

Materials and methods

The study was approved by the ethics committee of the National Cardiovascular Center (Osaka, Japan), and written informed consent was obtained from the parents of each patient.

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Table 1. Characteristics of study patients

Characteristic	Value
No. of patients	51
Age—median (range)	2 mo (4 days–12 mo)
Male/female	31/20
Body weight (kg)—median (range)	3.82 (1.74–9.9)
Height (cm)—median (range)	55 (43–78)
Diagnosis	
Transposition of great arteries	9
Tetralogy of Fallot	7
Ventricular septal defect and atrial septal defect	6
Coarctation of aorta and ventricular septal defect	5
Absent pulmonary valve syndrome	4
Ventricular septal defect	3
Total anomalous pulmonary venous return	3
Double-outlet right ventricle	3
Univentricular heart	2
Tricuspid atresia	2
Endocardial cushion defect	2
Congenital mitral valve regurgitation	2
Ebstein's anomaly	1
Hypoplastic left heart syndrome	1
Interruption of aortic arch	1
Operation	
Radical	45
Palliative	6

Patients

Fifty-one consecutive infants who had undergone cardiac surgery for congenital heart disease were included in this study (Table 1). The enrollment criteria were stable hemodynamics at the intensive care unit and leakage around the uncuffed endotracheal tube (3.0–4.5 mm ID) of less than 10% of the inspired tidal volume (V_T) at pressure control of 16 cm H_2O. We excluded candidates if they had chronic lung disease, central nervous system disorders, or diagnosed chromosome anomalies. During the measurement protocol, all patients were maintained in the supine position. Arterial blood pressure, heart rate, central venous pressure, and pulse oximeter signal (PM–1000; Nellcor, Hayward, CA, USA) were monitored continuously in all patients. In 15 patients, left atrial pressure was also monitored throughout the trial. During the CPAP trial, we did not administer any sedatives or opioids. Before extubation, to prevent postextubation laryngeal edema, we administered a single intravenous dose of dexamethasone (0.12–0.71 mg·kg^{-1}) in 38 patients who had shown no air leakage at all around the endotracheal tube at a pressure control of 16 cm H_2O [9].

Study protocol and measurements

We used V.I.P. Bird ventilators (Bird Corp., Palm Springs, CA, USA) with continuous-flow time- and patient-cycled pressure-limited ventilation. The initial ventilatory settings were as follows: assist control ventilation; respiratory rate, 20 breaths·min^{-1}; positive end-expiratory pressure, 3 cm H_2O; pressure control ventilation, 17 cm H_2O; inspiratory time (T_I), 0.8 s; continuous flow, 20 l·min^{-1}; and triggering sensitivity, 1.0 l·min^{-1}. When the patients recovered spontaneous breathing, we lowered the pressure control value, reduced triggering sensitivity to 0.4–0.8 l·min^{-1}, and, to prevent expiratory dyssynchrony between the patient and the ventilator, adjusted the termination criteria of inspiration to 5–20% of the peak inspiratory flow. Our policy for circulatory management is to maintain urine output > 1.5 ml·kg^{-1}·h^{-1} and ensure adequate peripheral circulation, to reverse the positive water balance established during cardiac surgery, and, depending on hemodynamics, to adjust catecholamines and vasodilators. Consequently, before the CPAP trials, 45 patients had received continuous dopamine infusion (1.1–5.5 μg·kg^{-1}·min^{-1}), 35 had received nitroglycerin (0.11–0.97 μg·kg^{-1}·min^{-1}), 9 epinephrine (9–56 ng·kg^{-1}·min^{-1}), and 7 had received milrinone (0.18–0.62 μg·kg^{-1}·min^{-1}).

We started taking measurements when the patients satisfied our weaning criteria: stable hemodynamics, pH greater than 7.30, ratio of Pa_{O_2} to $F_{I_{O_2}}$ greater than 200 in patients after radical operation, V_T greater than 5 ml·kg^{-1}, and respiratory rate less than 50 breaths·min^{-1} at a backup ventilatory rate of 6 breaths·min^{-1} and a

pressure control of 10–16 cm H_2O [7,8]. We recorded V_T baseline values, minute ventilation, respiratory rate, heart rate, arterial blood pressure, central venous pressure, and left atrial pressure. To monitor V_T and minute ventilation, we used a digital display on a ventilator graphic monitor (Partner Volume Monitors, Bird Corp.) [6]. Both V_T and minute ventilation data were standardized to body weight. Arterial blood samples were analyzed with a calibrated blood gas analyzer (ABL 505, Radiometer, Copenhagen, Denmark). In 35 patients, mixed venous oxygen saturation was measured through a central venous catheter. The rapid shallow breathing index (RSBI) was calculated by modifying an equation used for adults [10]:

$$\begin{aligned}&\text{RSBI}\left(\text{kg}\cdot\text{ml}^{-1}\cdot\text{min}^{-1}\right)\\&\quad=\text{respiratory rate}\left(\text{breaths}\cdot\text{min}^{-1}\right)/\text{V}_\text{T}\left(\text{ml}\cdot\text{kg}^{-1}\right)\\&\quad=\left(\text{respiratory rate}\right)^2/\left[\text{minute ventilation}\right.\\&\qquad\left.\left(\text{ml}\cdot\text{min}^{-1}\cdot\text{kg}^{-1}\right)\right],\end{aligned}$$

where Yang et al. [10] reported 105 as a threshold value to discriminate success and failure of extubation for adults. Standardized to a body weight of 50 kg, the threshold value is 5.25 $kg\cdot ml^{-1}\cdot min^{-1}$ ($= 105 \times 50/1000$).

After taking baseline measurements, we switched the ventilatory mode from assist control ventilation to CPAP. We used a positive end-expiratory pressure (3 cm H_2O), a continuous flow (20 $l\cdot min^{-1}$), and an inspired oxygen fraction that were equal to baseline values. We repeated the same measurements that were taken at baseline (V_T, minute ventilation, respiratory rate, heart rate, arterial blood pressure, central venous pressure, and left atrial pressure) at 1, 2, 3, 4, 5, 10, 15, 20, 25, and 30 min, and the mixed venous oxygen saturation measurement after 30 min of CPAP. Arterial blood samples were also analyzed after 10, 20, and 30 min of CPAP.

The primary physician was prepared to terminate the CPAP trial if the patient showed one or more of the following signs of distress: heart rate more than 200 beats·min^{-1}, sustained increase or decrease in heart rate or systolic blood pressure (>20%), decrease in arterial oxygen saturation (>5%), agitation, or diaphoresis [3]. We defined this as a protocol failure. In the absence of evidence of distress, the patient was extubated immediately after demonstrating tolerance of 30 min CPAP. After extubation, at the same inspired oxygen fraction as during the CPAP trial, the patient received supplemental oxygen with a head box. We repeated the measurements except for V_T and minute ventilation at 10 min and at 1, 2, and 3 h after extubation. Extubation was considered successful if reintubation was not carried out within 48 h of extubation: if there was reintubation, the extubation was considered a failure. For patients requiring reintubation within 48 h, the reasons for reintubation were recorded. All patients were followed until death or hospital discharge.

Data analysis and statistics

Data are presented as mean ± SD unless otherwise indicated. Comparisons of the values for the success and failure groups were made by the Mann-Whitney test or the χ^2 test. Using repeated-measures analysis of variance, mean values were compared across different points (baseline and 10, 20, and 30 min of CPAP) in the success group. When significance was observed, multiple-comparison testing of means was performed using the paired Student's *t*-test with Bonferroni's correction. In the failure group, comparison across different points was not performed because the sample was small ($n = 4$). Statistical significance was set at a level of $P < 0.05$.

Results

The infants ranged in age from 4 days to 12 months (median, 2 months), and body weight ranged from 1.74 to 9.9 kg (Table 1). Of the 51 infants, 50 completed the 30-min CPAP trial with stable hemodynamics. Subsequently, immediately after the CPAP trial, 46 infants (92%) underwent successful extubation, while 4 (8%) were reintubated within 48 h. Infants in the failure group tended to be smaller, to be subject to longer-term mechanical ventilation, and to have smaller crying vital capacity (Table 2).

The time courses of V_T, minute ventilation values, RSBI, and respiratory rate are shown in Figs. 1 and 2. These parameters were initially unstable during the first 5 min and then became stable from 10 to 30 min of CPAP. Table 3 shows the respiratory and hemodynamic variables for the success and failure groups at baseline, during CPAP, and after extubation. The hemodynamic variables prior to the CPAP trial did not significantly differ between the success and the failure group. The failure group showed a higher RSBI and a higher respiratory rate at 10 and 20 min of CPAP (Fig. 2). The failure group also showed significantly lower pH and higher Pa_{CO_2} after 10 min of CPAP (Fig. 3). All patients in the failure group had a pH less than 7.4 and a Pa_{CO_2} greater than 40 mmHg throughout the CPAP trial (Fig. 4). In contrast, 7 patients (15%) in the success group had a pH less than 7.4 after 10 min of CPAP, increasing to 8 (17%) at 20 min and 10 (22%) at 30 min (Fig. 4). The minute ventilation and Pa_{O_2} values showed no statistically significant differences between the groups (Table 3).

Table 2. Baseline ventilatory parameters of success and failure groups

Feature	Success group ($n = 46$)	Failure group ($n = 4$)
Age (mo)	3.0 (1–11)	0.5 (0–1.3)
Body weight (kg)	4.04 (3.11–7.07)	2.68 (2.32–3.00)*
Height (cm)	56 (50–69)	49 (47–50)*
Duration of mechanical ventilation (h)	27 (7–68)	242 (154–311)*
Crying vital capacity (ml·kg^{-1})	16.1 ± 5.9	10.3 ± 1.6*
Baseline mechanical ventilation		
Inspired oxygen fraction	0.41 ± 0.09	0.38 ± 0.05
Pressure control (cm H_2O)	12.6 ± 1.1	13.3 ± 2.5
Tidal volume (ml·kg^{-1})	9.2 ± 1.9	10.1 ± 1.3
Respiratory rate (breaths min^{-1})	26.4 ± 9.2	33.5 ± 18.5
Minute ventilation (l·min^{-1}·kg^{-1})	0.23 ± 0.07	0.31 ± 0.20

Plus-minus values are mean ± SD; other values are median (25th–75 percentile)
*$P < 0.05$ versus success group

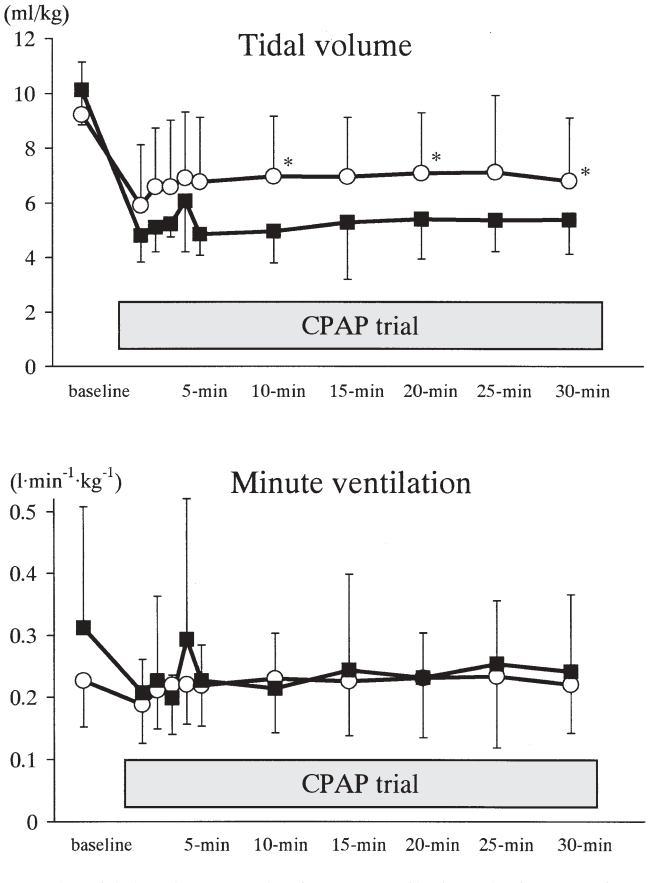

Fig. 1. Tidal volume and minute ventilation during continuous positive airway pressure (CPAP). (○) Success group; (■) failure group. Failure means that reintubation was performed within 48 h of extubation. *$P < 0.05$ versus baseline

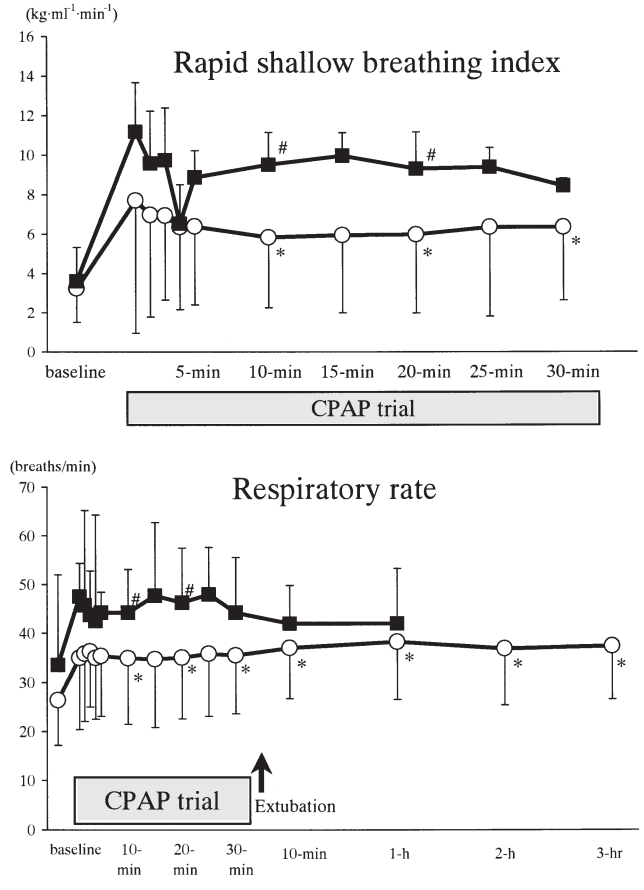

Fig. 2. Rapid shallow breathing index and respiratory rate during CPAP and after extubation. (○) Success group; (■) failure group. Failure means that reintubation was performed within 48 h of extubation. *$P < 0.05$ versus baseline; #$P < 0.05$ versus success group

We interrupted a single CPAP trial and switched back to assist control ventilation mode, because when CPAP was attempted, the patient demonstrated marked agitation and hypertension. Four patients (8%) were reintubated within 48 h. The reasons for reintubation were different in each case: apnea followed by severe pulmonary hypertension, insufficient respiratory drive, respiratory fatigue due to phrenic nerve

Table 3. Respiratory and hemodynamic variables during CPAP and after extubation

Variable	Outcome	Baseline	CPAP 10 min	CPAP 20 min	CPAP 30 min	Postextubation 10 min	Postextubation 1 h	Postextubation 2 h	Postextubation 3 h
V_T	Success	9.2 ± 1.9	7.0 ± 2.2*	7.1 ± 2.2*	6.8 ± 2.3*	nd	nd	nd	nd
(ml·kg^{-1})	Failure	10.1 ± 1.3	5.0 ± 1.2	5.4 ± 1.5	5.4 ± 1.3	nd	nd	nd	nd
RR	Success	26.4 ± 9.2	34.9 ± 13.4*	35.1 ± 12.5*	35.5 ± 12.0*	37.0 ± 10.3*	38.2 ± 11.7*	36.9 ± 11.5*	37.4 ± 10.8*
(breaths·min^{-1})	Failure	33.5 ± 18.5	44.3 ± 8.8#	46.3 ± 11.2#	44.3 ± 11.3	42.0 ± 7.8	42.0 ± 11.3	nd	nd
$\dot{V}_E$	Success	0.23 ± 0.07	0.23 ± 0.09	0.23 ± 0.10	0.22 ± 0.08	nd	nd	nd	nd
(l·min^{-1}·kg^{-1})	Failure	0.31 ± 0.20	0.21 ± 0.09	0.23 ± 0.07	0.24 ± 0.12	nd	nd	nd	nd
RSBI	Success	3.2 ± 1.7	5.8 ± 3.6*	6.0 ± 4.0*	6.4 ± 3.7*	nd	nd	nd	nd
(kg·ml^{-1}·min^{-1})	Failure	3.6 ± 1.7	9.5 ± 1.6#	9.3 ± 1.9#	8.4 ± 0.4	nd	nd	nd	nd
HR	Success	158 ± 20	159 ± 21	159 ± 20	159 ± 20	160 ± 20	159 ± 21	158 ± 22	157 ± 22
(beats·min^{-1})	Failure	176 ± 15	176 ± 15	176 ± 15	176 ± 15	171 ± 12	169 ± 16	nd	nd
Mean BP	Success	71 ± 13	71 ± 13	72 ± 13	72 ± 14	75 ± 12*	75 ± 14*	73 ± 13	74 ± 14
(mm Hg)	Failure	65 ± 9	64 ± 6	63 ± 8	64 ± 8	80 ± 10	86 ± 1	nd	nd
CVP	Success	8.0 ± 3.0	8.3 ± 3.7	8.1 ± 3.3	8.0 ± 3.3	8.0 ± 3.2	7.4 ± 3.4	7.2 ± 3.6	7.2 ± 3.4
(mm Hg)	Failure	8.0 ± 2.0	8.3 ± 1.5	8.7 ± 2.1	9.0 ± 2.0	9.0 ± 0.0	10.0 ± 0.0	nd	nd
LAP	Success	10.2 ± 3.7	10.5 ± 4.5	10.1 ± 4.0	10.0 ± 3.8	10.8 ± 3.7	10.6 ± 3.6	10.8 ± 3.7	10.4 ± 3.8
(mm Hg)	Failure	nd	nd	nd	nd	nd	nd	nd	nd
pH	Success	7.45 ± 0.04	7.43 ± 0.04	7.43 ± 0.04	7.44 ± 0.04	7.43 ± 0.04	7.44 ± 0.04	7.44 ± 0.04	7.44 ± 0.04
	Failure	7.43 ± 0.07	7.37 ± 0.03#	7.36 ± 0.03#	7.36 ± 0.03#	7.36 ± 0.07	7.30 ± 0.06	nd	nd
Pa_{CO_2}	Success	38.9 ± 4.7	41.0 ± 5.0*	40.7 ± 4.7	40.6 ± 5.3	41.1 ± 5.6*	40.8 ± 5.1	40.4 ± 4.7	39.9 ± 4.9
(mm Hg)	Failure	38.9 ± 6.2	46.1 ± 2.9#	46.5 ± 4.7#	46.8 ± 3.4#	43.1 ± 7.5	53.5 ± 1.3#	nd	nd
Pa_{O_2}	Success	129 ± 45	119 ± 40	120 ± 38	121 ± 38	133 ± 67	131 ± 53	126 ± 53	128 ± 49
(mm Hg)	Failure	108 ± 53	98 ± 47	104 ± 53	101 ± 53	116 ± 101	80 ± 3	nd	nd
Lactate	Success	1.4 ± 0.6	1.4 ± 0.5	1.3 ± 0.5	1.3 ± 0.5	1.7 ± 0.7*	1.5 ± 0.7	1.4 ± 0.5	1.3 ± 0.6
(mmol·l^{-1})	Failure	1.2 ± 0.2	1.1 ± 0.2	1.0 ± 0.3	1.0 ± 0.1	1.9 ± 1.6	1.1 ± 0.3	nd	nd
$S\bar{v}_{O_2}$	Success	65 ± 8			67 ± 9*				
(%)	Failure	68 ± 2			77 ± 0.5*#				

BP, blood pressure; CPAP, continuous positive airway pressure; CVP, central venous pressure; F, failure group; HR, heart rate; LAP, left atrial pressure; RR, respiratory rate; RSBI, rapid shallow breathing index; S, success group; $S\bar{v}_{O_2}$, mixed venous oxygen saturation; $\dot{V}_E$, minute ventilation; V_T, tidal volume. *$P < 0.05$ versus baseline; #$P < 0.05$ versus success group

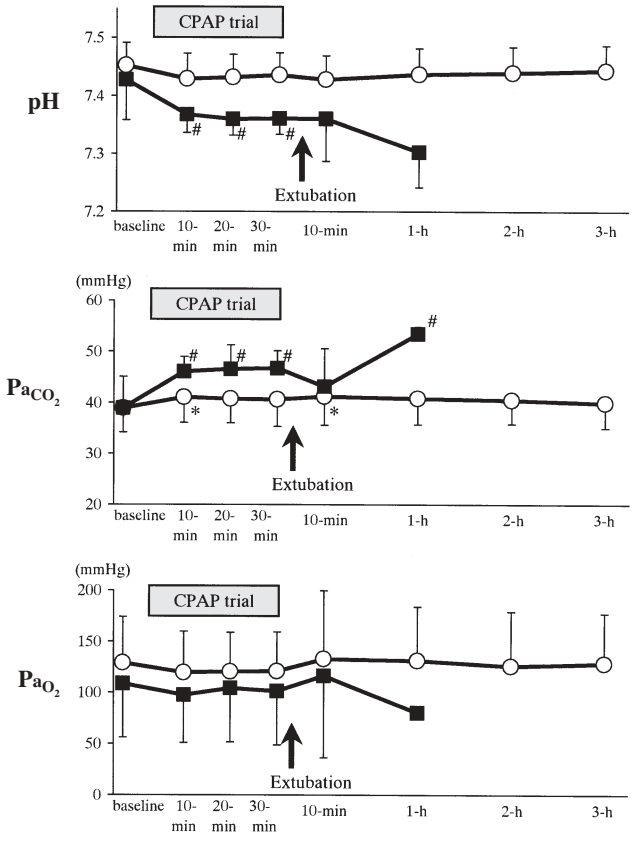

Fig. 3. Change in pH, Pa_{CO_2}, and Pa_{O_2} during CPAP and after extubation. (○) Success group; (■) failure group. Failure means that reintubation was performed within 48 h of extubation. $^{*}P < 0.05$ versus baseline; $^{\#}P < 0.05$ versus success group

palsy, and upper airway obstruction caused by glottic granuloma. In Case 1 extubation occurred 3 days after the CPAP trial, and in Case 2 6 days after the CPAP trial. In Case 3, after plication of the diseased diaphragm, extubation was performed on the day following the plication surgery. The patient in Case 4, owing to severe glottic and supraglottic granuloma, underwent tracheostomy before being weaned from the ventilator.

None of these patients died in the intensive care unit. The median length of stay in the intensive care unit was 4 days after surgery, ranging from 2 to 66 days. After a median postoperative stay of 46 days, 49 patients were discharged from the hospital. Two patients from the success group died in the ward. One had received a Jatene procedure for transposition of the great arteries and died on postoperative day 7 from thrombotic occlusion of the coronary artery. The other, who had undergone a Fontan operation for univentricular heart, succumbed to progressive heart failure on postoperative day 88.

Discussion

The main findings of this study are that ventilatory parameters became stable after 10 min of CPAP in post—cardiac surgery infants; 50/51 (98%) were able to safely undergo a 30-min CPAP trial, and 46/50 (92%) were extubated successfully immediately after the trial; and the failure group had lower pH, higher Pa_{CO_2}, and more rapid shallow breathing during CPAP.

Clinical implications

The most common methods of discontinuing mechanical ventilation in adults are synchronized intermittent mandatory ventilation, pressure support ventilation, and T-piece trials [1,2]. Using 2-h T-piece trials, Esteban et al. [3] initially reported earlier and successful extubation in adult medical or surgical patients, compared with synchronized intermittent mandatory ventilation and pressure support ventilation; more recently, half-hour T-piece trials were shown to be as effective as 2-h trials [4]. For infants, however, there have been few reports of spontaneous breathing trials [5,6,11]. In the present study of infants, we found that tolerance of 30-min CPAP trials was 92% predictive of successful extubation. Although V_T, minute ventilation values, respiratory rate, and RSBI were initially unstable during the first 5 min, they were stable from 10 to 30 min of CPAP. While conventional weaning strategies require stepwise decreases in support level and frequent clinical evaluation, short CPAP trials save time and labor of the intensive care staff.

Our findings show that, compared with infants who underwent successful extubation, the infants who were reintubated within 48 h were smaller, had received longer-term mechanical ventilation, and had smaller crying vital capacity (Table 2). These findings correlate with previous reports for children, although the subjects were older than those in our study [6,12]. In a retrospective review, Edmunds showed that the children in whom extubation failed were younger and had received mechanical ventilation longer than those who were successfully extubated [12]. In a prospective study, Thiagarajan et al. [6] similarly reported that children who were successfully extubated received mechanical ventilation for a shorter time, with better lung compliance and oxygenation.

Although the baseline pH and Pa_{CO_2} were the same for both groups, during CPAP the failure group had greater respiratory acidosis (Fig. 4). Jubran et al. [13] reported that about half of adult patients who failed spontaneous breathing trials had an increase in Pa_{CO_2} of 10 mmHg or more. Rather than being due to decreased minute ventilation, this hypercapnia usually results from rapid shallow breathing, which causes an increase

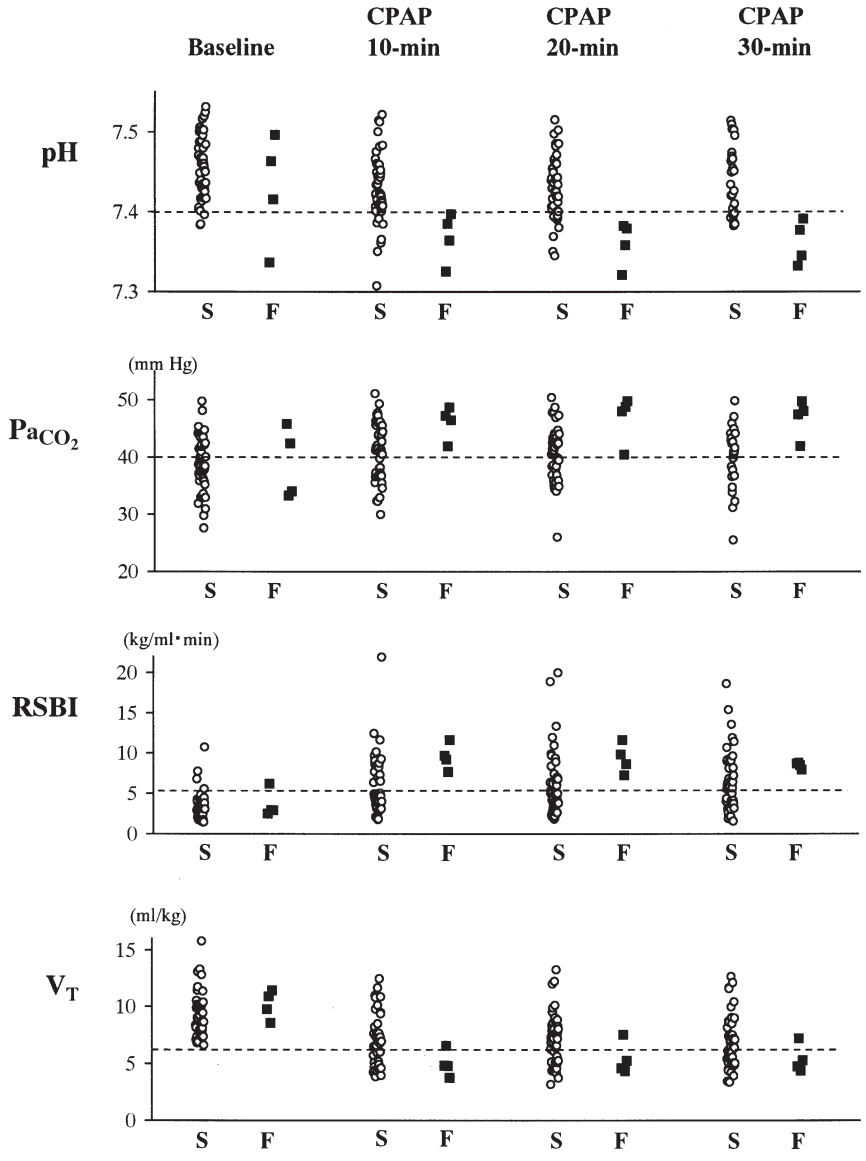

Fig. 4. Values of pH, Pa_{CO_2}, rapid shallow breathing index, and tidal volume at baseline and after 10, 20, and 30 min of CPAP. *Top to bottom*: *dotted lines* represent pH = 7.4, Pa_{CO_2} = 40 (mmHg), RSBI = 5.25 ($kg \cdot ml^{-1} \cdot min^{-1}$), and V_T = 6 (ml/kg), respectively. (○) Success group; (■) failure group. Failure means that reintubation was performed within 48 h of extubation. *F*, failure group; *RSBI*, rapid shallow breathing index; *S*, success group; V_T, tidal volume

in dead-space ventilation [1,13]. RSBI is, therefore, regarded as the most reliable way of predicting the success or failure of respiratory weaning in adults [10]. However, the usefulness of RSBI for similar prediction in infants or children is controversial [6,14,15]. Whereas Thiagarajan et al. [6] reported that RSBI enabled reliable prediction of pediatric extubation failure, Khan [14] and Venkataraman [15] reported conflicting results. Although each patient in the failure group showed RSBI $> 5.25\,kg \cdot ml^{-1} \cdot min^{-1}$, we found there was some overlap between the success and failure groups (Fig. 4). Other ventilatory parameters, including V_T and minute ventilation, showed wide variation and did not correlate well with extubation success or failure.

In ventilator-dependent adults, unsuccessful attempts at spontaneous breathing cause cardiovascular stress [1,16]. There are two main contributing factors: respiratory efforts cause negative swings in intrathoracic pressure, thus increasing right and left ventricular afterloads; and cardiac function cannot meet the increased oxygen demand when positive pressure ventilation is discontinued [1]. Although some patients had complicated heart anomalies, no infants in this study showed signs of cardiovascular deterioration, such as decreased blood pressure or elevated central venous pressure or left atrial pressure during CPAP (Table 3). In fact, in both the success and the failure groups, after 30 min of CPAP there was increased mixed venous oxygen saturation and serum lactate values were stable (Table 3). Before the patients were enrolled in the study, the vasopressor and volume had already been adjusted to levels compatible with tolerance of the hemodynamic changes that may ensue during and after extubation. This may have introduced a bias toward

stable hemodynamics during CPAP and successful extubation.

For pediatric patients, postextubation airway stenosis is a serious problem that is likely to necessitate reintubation and prolongation of intensive care [9]. Irrespective of the weaning mode, this complication might occur, and in this study, even though dexamethasone pretreatment was administered, airway obstruction due to severe glottic granuloma occurred in one infant.

CPAP settings

Rather than using a T-piece trial, we applied CPAP of 3 cm H_2O. Although the T-piece trial is a simpler procedure that is likely to lower the respiratory workload related to the resistance of the ventilator circuit [3,4,11], we preferred CPAP, for several reasons. First, opening an infant's airway to the atmosphere through an endotracheal tube may result in atelectasis because of chest wall compliancy. In difficult-to-wean adults, a T-piece trial lasting for more than 30–60 min may increase the respiratory effort considerably, mainly due to worsening respiratory mechanics [1,13]. Application of low CPAP may prevent atelectasis in infants and minimize the deterioration in respiratory mechanics. Second, the use of a ventilator and graphic monitor allowed us to continuously monitor respiratory variables such as respiratory rate, V_T, and minute ventilation in the same way as during our daily clinical care. By alerting the physician to early signs of respiratory distress, close attention to these variables improves safety. Thiagarajan et al. [6] similarly applied CPAP for a few minutes and used a digital output from the ventilator to assess weaning parameters. Third, the method has other practical advantages. Whereas other studies measured volumes using a pneumotachograph attached to the patient's endotracheal tube [14,15], the application of CPAP required no additional equipment; it minimized dead space or resistance due to the equipment, and it did not require disconnection of the patients from ventilators.

The common methods of weaning involve gradually decreasing ventilatory assistance by lowering the number of assisted breaths or the level of pressure. This gradually increases the respiratory workload, and the workload after extubation is smaller than that during CPAP [7,8]. Therefore, providing that the clinical and gas exchange status is satisfactory at a low level of ventilatory support, the switch to CPAP could be a mild short-term trial to examine the readiness for liberation from mechanical ventilation. The optimal duration of a spontaneous breathing trial has not been established in infants; we therefore arbitrarily chose 30 min as the duration of CPAP in this study. In fact, we observed that 10 min were required for ventilatory and hemodynamic variables to become stable after starting CPAP (Figs. 1 and 2). This may suggest that 30 min of observation for the CPAP trial was as effective as a longer trial. This speculation correlates with Esteban's reports that 30-min T-piece trials are as effective as 2-h trials in adults [4]. Recently, Furias et al. [7] compared the percentage of successful extubations of pediatric intensive care patients (aged 1 month to 15 years) after a spontaneous breathing trial performed with either pressure support ventilation of 10 cm H_2O or a T-piece for 2 h. The two spontaneous breathing trials had similar incidences of trial interruption (21% and 23%) and reintubation (15% and 13%). In our study, one patient in the failure group was reintubated 1 h after extubation due to phrenic nerve palsy. It is possible that this respiratory failure could have been foreseen if the CPAP trial was longer. On the other hand, extended CPAP may cause respiratory distress. Tapia et al. [5] reported that the extubation failure rates for very-low-birthweight infants were similar with the strategy of direct extubation from intermittent mandatory ventilation (2/30, 7%) and the use of CPAP trials lasting 12–24 h (4/28, 14%). They speculated that the use of a narrow endotracheal tube for small infants may increase the work of breathing and cause respiratory fatigue. Further study is needed to determine the optimal duration of CPAP trials for infants.

Limitations

The current study has several limitations. First, although several infants had congestive lungs, probably due to heart failure, none of the subjects had primary lung diseases. More seriously compromised infants or ventilator—dependent infants may respond to CPAP trials quite differently. Second, because the number of enrolled patients was small ($n = 51$), and few patients ($n = 4$) were in the failure group, it was difficult to delineate which factors or combination of factors are predictive of success or failure of extubation. Third, because we did not measure esophageal pressure, this report does not provide any information about the relationship between CPAP and the work of breathing. Fourth, we did not evaluate the effects of different types of ventilator on the results of the CPAP trial. Finally, because our policy of hemodynamic management was neither randomized nor strictly prescribed, we cannot exclude the possibility of enrollment bias.

In conclusion, the ventilatory pattern and hemodynamics became stable after 10 min of CPAP. Ninety-two percent of post—cardiac surgery infants were successfully extubated after 30 min of CPAP trial. CPAP trials may be a safe method to help physicians

perform smooth extubation in infants after cardiac surgery.

References

1. Tobin MJ (2001) Advances in mechanical ventilation. N Engl J Med 344:1986–1996
2. Alía I, Esteban A (2000) Weaning from mechanical ventilation. J Crit Care 4:72–80
3. Esteban A, Frutos F, Tobin MJ, Alía I, Solsona JF, Vallverdú I, Fernández R, De La Cal MA, Benito S, Tomás R, Garriedo D, Macías S, Blanco J (1995) A comparison of four methods of weaning patients from mechanical ventilation. N Engl J Med 332:345–350
4. Esteban A, Alía I, Tobin MJ, Gil A, Gordo F, Vallverdú I, Blanch L, Bonet A, Vazquez A, de Pablo R, Torres A, de la Cal MA, Macías S, for the Spanish lung failure collaborative group (1999) Effect of spontaneous breathing trial duration on outcome of attempts to discontinue mechanical ventilation. Am J Respir Crit Care Med 159:512–518
5. Tapia JL, Bancalari A, González A, Mercado ME (1995) Does continuous positive airway pressure (CPAP) during weaning from intermittent mandatory ventilation in very low birth weight infants have risks or benefits? A controlled trial. Pediatr Pulmonol 19:269–274
6. Thiagarajan RR, Bratton SL, Martin LD, Brogan TV, Taylor D (1999) Predictors of successful extubation in children. Am J Respir Crit Care Med 160:1562–1566
7. Imanaka H, Nishimura M, Miyano H, Uemura H, Yagihara T (2001) Effect of synchronized intermittent mandatory ventilation on respiratory workload in infants after cardiac surgery. Anesthesiology 95:881–888
8. Takeuchi M, Imanaka H, Miyano H, Kumon K, Nishimura M (2000) Effect of patient-triggered ventilation on respiratory workload in infants after cardiac surgery. Anesthesiology 93: 1238–1244
9. Anene O, Meert KL, Uy H, Simpson P, Sarnaik AP (1996) Dexamethasone for the prevention of postextubation airway obstruction: a prospective, randomized, double-blinded, placebo-controlled trial. Crit Care Med 24:1666–1669
10. Yang KL, Tobin MJ (1991) A prospective study of indexes predicting the outcome of trials of weaning from mechanical ventilation. N Engl J Med 324:1445–1450
11. Farias JA, Retta A, Alía I, Olazarri F, Esteban A, Golubicki A, Allende D, Maliarchuk O, Peltzer C, Ratto ME, Zalazar R, Garea M, Moreno EG (2001) A comparison of two methods to perform a breathing trial before extubation in pediatric intensive care patients. Intensive Care Med 27:1649–1654
12. Edmunds S, Weiss I, Harrison R (2001) Extubation failure in a large pediatric ICU population. Chest 119:897–900
13. Jubran A, Tobin MJ (1997) Pathophysiologic basis of acute respiratory distress in patients who fail a trial of weaning from mechanical ventilation. Am J Respir Crit Care Med 155:906–915
14. Khan N, Brown A, Venkataraman ST (1996) Predictors of extubation success and failure in mechanical ventilated infants and children. Crit Care Med 24:1568–1579
15. Venkataraman ST, Khan N, Brown A (2000) Validation of predictors of extubation success and failure in mechanically ventilated infants and children. Crit Care Med 28:2991–2996
16. Lemaire F, Teboul JL, Cinotti, Giotti G, Abrouk F (1988) Acute left ventricular dysfunction during unsuccessful weaning from mechanical ventilation. Anesthesiology 69:171–179