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Crying Vital Capacity and Maximal Inspiratory Pressure as Clinical Indicators of Readiness for Weaning of Infants Less Than a Year of Age

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Weaning from prolonged mechanical ventilation is a major problem in management of infants with postoperative respiratory failure or severe pulmonary disease. Arterial blood-gas data are reported to be insufficient to warrant successful removal of the endotracheal tube.[1,2] Although crying vital capacity and maximal inspiratory pressure have been clinically used as criteria for endotracheal extubation,[3] quantitative analyses of the reliability of these modalities as indicators of readiness for tracheal extubation are scant. We have studied these variables quantitatively in terms of weaning infants less than a year of age.

MATERIALS AND METHODS

Twenty-five consecutive patients less than a year of age who had needed mechanical ventilation for more than 24 hours were studied. They were admitted to the Intensive Care Unit at the Osaka University Hospital between January 1975 and April 1978. Patients who had organic brain damage or were moribund were excluded from the study. All patients were postoperative; 11 had had open-heart surgery. Eight patients who had been treated by general surgical procedures were newborns. None had intrinsic pulmonary disease. A summary of the cases is given in table 1. Thirteen patients were successfully weaned at the first attempt and needed no reintubation of the trachea. Six patients needed tracheal reintubation, but were successfully weaned at the second attempt. Six patients could not be weaned (table 2). We divided the patients into two groups. Group I consisted of 19 patients whose tracheas were successfully extubated; 13 of these were successfully weaned at the first attempt, six at the second attempt. Group II consisted of six patients in whom 14 attempts to extubate the trachea were made, 12 of which were followed by reintubation. Two patients in Group II were counted twice because tracheal extubation was attempted twice.

TABLE 1. Summary of Cases

	Number of Patients	Age (Months)
Cardiac surgery	11	7.5 ± 4.4
Atrial septal defect or ventricular septal defect with pulmonary hypertension	4	
Transposition of great vessels	4	
Total anomalous pulmonary venous drainage	2	
Palliative (Waterstone)	1*	
General surgery	14	0.9 ± 1.7
Tracheoesophageal fistula	5 (1*)	
Omphalocele	3	
Gastric perforation	3	
Diaphragmatic hernia	2	

* Cyanotic.

TABLE 2. Results of Weaning in 25 Infants

	Number of Infants		
	Successfully Weaned at First Attempt	Re-intubated but Successfully Weaned at Second Attempt	Weaning Failed in Spite of Repeated Attempts to Extubate the Trachea
Cardiac surgery	5	3	3
General surgery	8	3	3
TOTAL	13	6	6

The weaning protocol throughout the study was intermittent mandatory ventilation (IMV), 25–30/min, and 5 cm H_2O positive end-expiratory pressure (PEEP). When Pa_{O_2} was 60–80 torr and Pa_{CO_2} less than 50 torr, we decreased the inspired oxygen concentration (FI_{O_2}) initially. When Pa_{O_2} 60–80 torr could be maintained at FI_{O_2} 0.5, we decreased the rate of IMV. When a Pa_{CO_2} of less than 50 torr could be maintained at an IMV rate of 5/min, spontaneous ventilation with continuous positive airway pressure (CPAP) was begun. We then reduced the end-expiratory pressure. When the patient could maintain a Pa_{O_2} of more than 60 torr and Pa_{CO_2} of less than 50 torr with CPAP 2 cm H_2O at FI_{O_2} less than 0.5 for more than 60 min, we removed the endotracheal tube. At extubation, the pa-

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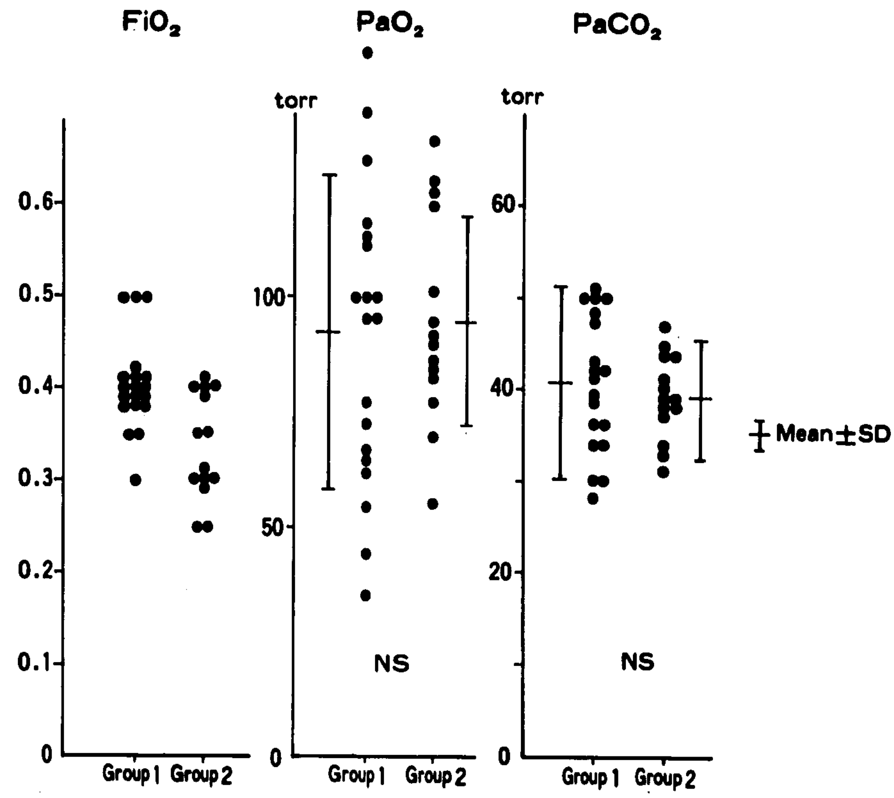

FIG. 1. Pa_{O_2}, Pa_{CO_2}, and FI_{O_2} values prior to tracheal extubation in the two groups.

tient's cardiovascular status should be stable, and there should be no major neurologic disturbance. For the patient with cyanotic heart disease, a Pa_{O_2} of more than 35 torr is used instead of 60 torr. Every patient received intensive physiotherapy and nursing care after tracheal extubation.

The criteria for reintubation of the trachea in the present study were: Pa_{O_2} less than 50 torr and Pa_{CO_2} more than 50 torr at FI_{O_2} 0.5, with one of the following symptoms: tachypnea retractions, blood pressure instability, marked restlessness and agitation, or decreased consciousness.

Crying vital capacity (CVC) and maximal inspiratory pressure (MIP) were measured just prior to tracheal extubation in every patient who met our criteria of extubation. By flicking the soles of the feet, we made the patient cry with the endotracheal tube in place and recorded the expired tidal volume. Gas volumes were measured by means of a hot-wire flowmeter with an integrator[4] (Minato Medical Science, Osaka, Japan). The transducer was placed either at the oral end of the endotracheal tube or at the expired limb of the CPAP system, when the tidal volume was less than 10 ml.[5]

Maximal inspiratory pressure was measured by means of a differential manometer with an amplifier (Validyne NM45-4, Engineering Corp.). The pressure was measured at the oral end of the endotracheal tube. When the endotracheal tube is occluded at the end of expiration, patients start gasping. Usually the fourth or fifth gasp made the maximal negative pressure.

Statistical analysis was performed by the Student *t* test. Differences were considered significant when P was <0.05.

RESULTS

Figure 1 shows the arterial blood-gas data prior to tracheal extubation in both groups. FI_{O_2}s were between 0.25 and 0.5 in both groups. Pa_{O_2} and Pa_{CO_2} fulfilled the criteria for tracheal extubation in all patients studied. There was no significant difference between Pa_{O_2} or Pa_{CO_2} values in the two groups.

Tidal volume at rest (TV) and CVC at the time of tracheal extubation are shown in figure 2. In Group I, tidal volume at rest was 7.5 ± 2.1 ml/kg, and CVC was 22.5 ± 5.9 ml/kg. In Group II, tidal volume at rest was 6.3 ± 2.4 ml/kg, and CVC was 11.8 ± 3.1 ml/kg. Tidal volumes at rest in the two groups did not differ significantly, but CVCs differed significantly ($P < 0.001$).

Maximal inspiratory pressures at the time of tracheal extubation are shown in figure 3. Maximal inspiratory pressures were −34.0 cm H_2O or more in Group I, with an average of −56.6 ± 16.6 cm H_2O. Maximal inspiratory pressures were −56.0 cm H_2O or less in Group II, with an average of −37.1 ± 10.2 cm H_2O.

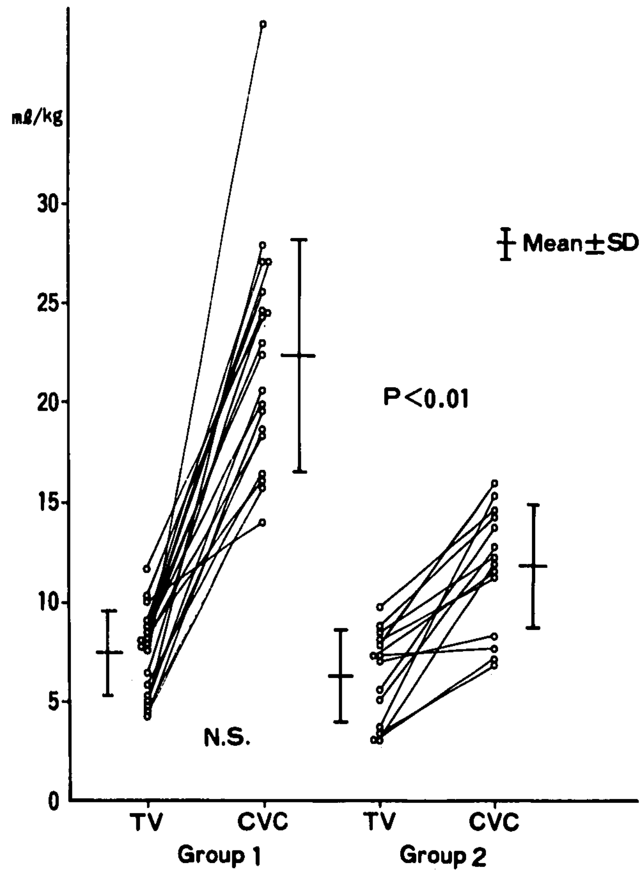

FIG. 2. Tidal volumes at rest (TV) and crying vital capacities (CVC) in the two groups.

The difference between the mean values was significant, $P < 0.001$.

Figure 4 shows the relationships between CVC and maximal inspiratory pressure measured simultaneously prior to tracheal extubation in the two groups.

Discussion

The potential hazards of prolonged mechanical ventilation are well known, but early or premature weaning is also deleterious, and may sometimes cause pulmonary complications. Clinical criteria for proper weaning are needed. The maintenance of adequate blood-gas values when the infants are being treated with CPAP prior to tracheal extubation is often insufficient to warrant successful weaning.[1]

Determination of CVC has been reported to be a safe, rapid, noninvasive test of neonatal pulmonary function, and has been a valuable aid in assessing pulmonary function in neonates with respiratory failure.[6,7] Maximal inspiratory pressure has also been used as one of the clinical criteria for weaning in adults.[3,8,10] But quantitative studies of CVC and maximal inspiratory pressure in terms of weaning in infants are still scant.

In infants, because of lack of patient cooperation, variables to predict effective cough, deep breaths, and forceful cry are difficult to measure, but these should be evaluated prior to tracheal extubation. We have shown that, when infants are quietly breathing during administration of CPAP, we could not predict whether their tracheas could be successfully extubated on the basis of arterial blood-gas and tidal volume values. But once an infant was forced to cry, CVCs were three times the resting tidal volume in Group I and less than twice the resting tidal volume in Group II. Bendixen *et al.*[8] stated from their experience that, for an adult to be weaned from mechanical ventilation, the vital capacity should be greater than 10 ml/kg. This corresponds to approximately twice the normal tidal volume. Infants have greater body length-to-body weight ratios than adults, and lung volumes will usually correlate with body length.[9] This might explain why our infants had CVCs approximately three times their tidal volumes. The measurement of CVC was performed by the hot-wire method.[4] The hot-wire method is satisfactory in detecting an infant's expired tidal volume either at the oral end of the endotracheal tube or at the expired limb of the CPAP system while the infant is breathing during the constant flow of gases.[5] But it is only valid when the flow is across the fixed diameter of the transducer. Thus, we might have underestimated the volume, if there had been leakage around the endotracheal tube. We did not measure the amount of air leakage. However, it is our practice to use an endotracheal tube as large as possible and to allow minimal gas leakage during maximal inflation of

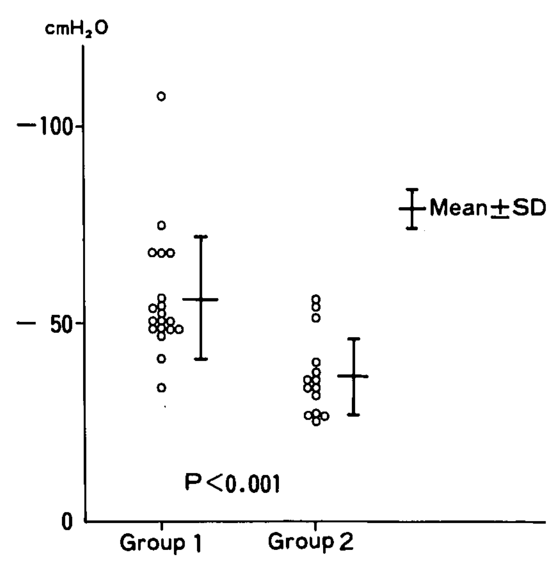

FIG. 3. Maximal inspiratory pressures (MIP) in the two groups.

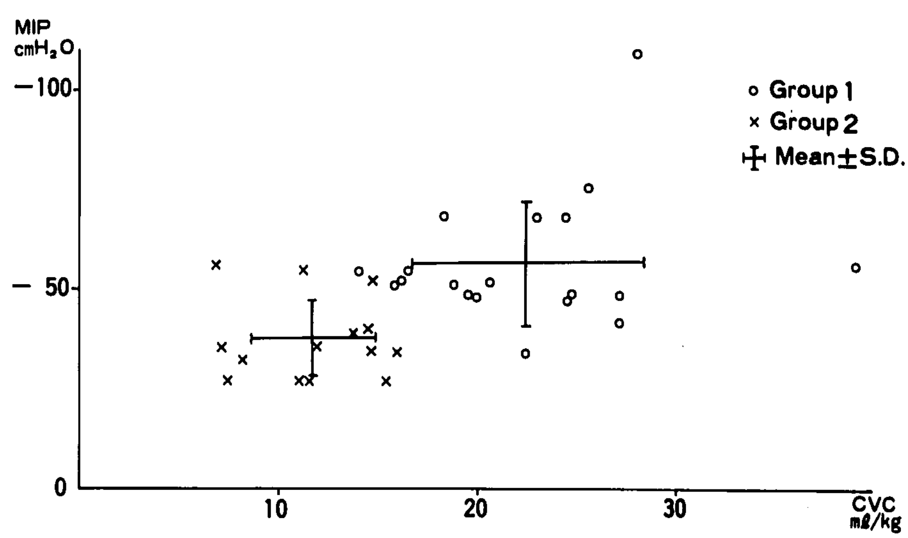

FIG. 4. Relationships between crying vital capacity (CVC) and mean inspiratory pressure (MIP) measured simultaneously in the two groups.

the lungs. We are certain that any leakages would have been approximately the same in the two groups. Measurement of maximal inspiratory pressure is a simple and useful way to evaluate a patient's muscular strength and/or the state of the chest wall and lungs. It is also a safe maneuver, because there is no change in lung volume except for a minimal compression and expansion of gases, and the transpulmonary pressure cannot change even when the infant generates negative pressure to as much as 100 cm H_2O. Maximal inspiratory pressure should also depend upon respiratory drive.[3] We excluded those infants in whom the central nervous system was depressed. Bendixen *et al.*[8] stated that a pressure exceeding −20 cm H_2O was considered a minimum reserve in a patient with normal lungs. On the other hand, Sahn and Lakshminarayan[10] showed that patients with maximal inspiratory pressures greater than −30 cm H_2O were always able to have mechanical ventilation discontinued safely. We have shown in our groups of infants a greater value of maximal inspiratory pressure than those proposed for adults. On an average, a maximal inspiratory pressure of −56.6 cm H_2O was produced by those infants whose tracheas were successfully extubated. Although there was a significant difference between the mean values in the two groups, there was enough overlap in individual measurements. When CVC and maximal inspiratory pressure were combined, they provided a useful indication of whether the infant could be successfully weaned from prolonged mechanical ventilation. Figure 4 shows that an infant who has a CVC greater than 15 ml/kg and a maximal inspiratory pressure greater than −45 cm H_2O can be safely weaned from prolonged mechanical ventilation. In addition to the above determinations, it is imperative to assure the infant's cardiovascular status is stable and there is no central nervous system depression or major brain damage.

The ease and safety with which these measurements can be performed with a hot-wire respirometer and a manometer make them useful for prediction of infants' respiratory reserves after prolonged mechanical ventilation.

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