Noninvasive ventilation via bilevel positive airway pressure support in pediatric patients after cardiac surgery

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Background: **Noninvasive bilevel positive airway pressure (BiPAP) support ventilation applied by nasal mask in children with impending respiratory failure enhances oxygenation/ventilation, decreases the work of breathing, and may obviate the need for an artificial airway. This study was to provide a prospective evaluation of clinical experience in this special population, suggesting a wider role for this less intrusive ventilatory support modality.**

Methods: **Twenty-five patients (3 months to 11 years, mean 2.3 years) who underwent corrective cardiac surgery and developed respiratory insufficiency after extubation were enrolled in the study. All patients required airway support or oxygenation/ventilatory support and were firstly treated with noninvasive BiPAP ventilation before re-intubation. The changes of clinical symptoms and arterial blood gas were measured.**

Results: **The 25 patients with 30 episodes of respiratory insufficiency requiring airway support or oxygenation/ventilatory support were treated with BiPAP ventilation with a mean duration of 1.96 days (range, 0.03 to 12 days). No major complications were observed. Twenty-five episodes (83.3%) benefited from BiPAP and avoided re-intubation. One hour after institution of BiPAP, the patients showed an acute improvement of oxygenation. pH increased from 7.37±0.02 to 7.41±0.01, SaO_2 increased from 93.8±1.0% to 97.7±0.4%, PaO_2/FiO_2 increased from 189.9±25.0 to 253.6±21.2 mmHg, and A-aDO_2 decreased from 241.8±18.7 to 182.1±16.5 mmHg (all P<0.05). Four hours after BiPAP, $PaCO_2$ significantly decreased from 44.0±2.1 to 38.9±0.8 mmHg (P<0.05). Meanwhile, heart rate decreased from 157±4 to 139±4 beats/minute, respiratory rate decreased from 46±2 to 37±2 breaths/minute, rate-pressure product decreased from 17 230±685 to 14 046±423 mmHg · beats/minute (all P<0.05). Five episodes in 4 patients were unable to stabilize progression of respiratory failure and an artificial airway was subsequently placed. All patients survived with a mean mechanical ventilation duration of 3.4 days and an ICU stay of 10.6 days.**

Conclusions: **Noninvasive nasal mask BiPAP can be safely and effectively used in children after cardiac surgery to improve oxygenation/ventilation, decrease the work of breathing. It may be particularly useful in patients whose underlying condition warrants avoidance of re-intubation.**

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Introduction

Respiratory insufficiency is commonly seen in children with congenital heart disease after cardiac surgery. Invasive mechanical ventilation with an endotracheal tube is routinely used in the treatment, but an artificial airway increases the risk of complications such as barotraumas and ventilator associated pneumonia.[1,2] Noninvasive positive airway pressure ventilation is non-invasive, easy to set up and wean, more comfortable, and less expensive. It produces fewer complications. A portable noninvasive bilevel positive airway pressure (BiPAP; Respironics Inc; Murrysville, Pa) system combines inspiratory pressure support ventilation and expiratory positive airway pressure administered through a nasal mask. This system provides therapy similar to continuous positive pressure devices but may offer additional benefits such as inspiratory pressure support and correction for mask air leak.

Experience in adult patients has demonstrated that BiPAP is effectively and safely used in patients with respiratory insufficiency owing to chronic obstructive pulmonary disease.[3,4] The role of noninvasive BiPAP ventilation was previously evaluated in pediatric patients with status asthmaticus[5,6] but not in critically ill pediatric patients after cardiac surgery. We initiated a prospective study to identify subgroups of critically ill pediatric patients after cardiac surgery who could benefit from BiPAP, suggesting a wider role of this less intrusive ventilatory support modality.

Methods

Patient selection

From January 2005 to December 2005, all patients undergoing cardiac corrective surgery who developed respiratory insufficiency after extubation and required airway support or oxygenation/ventilatory support were treated with noninvasive BiPAP ventilation before re-intubation. A total of 25 patients (12 males and 13 females) with a mean age of 2.3 years (range, 3 months to 11 years) and a mean body weight of 9.8 kg (range, 4 to 25 kg) who had received noninvasive BiPAP ventilation were enrolled in this study. The cardiopulmonary bypass duration was 116±8 minutes, and the aortic cross-clamp time was 81±6 minutes. The patient characteristics are shown in Table 1.

Nasal mask noninvasive BiPAP ventilation

If patients undergoing cardiac surgery developed respiratory insufficiency after extubation after cardiac surgery and required airway support or oxygenation/ventilatory support, they were treated with noninvasive BiPAP ventilation before re-intubation. The commonly seen causes of respiratory insufficiency after cardiac surgery were pulmonary edema, pneumonia and atelectasis, both in the patients with increased and decreased pulmonary blood flow before operation. The patients ready for BiPAP should be conscious and cooperative with regular spontaneous breath, stable hemodynamics, no risk for asphyxia (such as aspiration, serious gastrointestinal tract hemorrhage or severe airway secretions) nor facial trauma, and tolerable to nasal mask.

A portable noninvasive bilevel positive airway pressure (BiPAP; Respironics Inc; Murrysville, Pa) system was developed with high flow but low pressure, good air leakage compensation, auto-flow track and good synchronized trigger. A spontaneous/timed operating mode (S/T) combined inspiratory pressure support ventilation (IPAP) and expiratory positive airway pressure (EPAP) administered through a nasal mask. A backup rate was added to assist with inadequate minute ventilation or apnea. In order to enhance comfort and compliance, the pressure of assistant ventilation must be adjusted from the low level. Usually IPAP was adjusted from 6-8 cmH_2O, and EPAP from 3-4 cmH_2O. The parameters increased gradually to appropriate clinical setting after 5-20 minutes.

BiPAP was initiated to prevent re-intubation and served as life-support function. The patients were closely monitored in terms of (1) vital signs and general appearance; (2) respiratory rate, tidal volume, dyspnea, breath effort, retraction, use of accessory muscles, patient-ventilator synchrony, and chest X-ray; (3) oxygen saturation and blood gas; (5) abdominal distention, exacerbation of gastroesophageal reflux disease, aspiration, pneumothorax, irritation of the eyes and skin, sedation for anxiety, and so on.

BiPAP ventilation was evaluated by the effect of BiPAP on the decrease of heart rate, respiratory rate, and oxygen requirement, and the increase of oxygen saturation.[3] Enhancement in ventilation was judged by decreased concentrations of PCO_2 and bicarbonate. These measurements suggested that BiPAP ventilation is effective[7] and that it can be continued. Otherwise, either re-adjusting of the ventilator parameters or termination of noninvasive BiPAP is considered for re-intubation and invasive mechanical ventilation.

The indications for terminating BiPAP included no obvious relief of dyspnea nor significant improvement of blood gas, hemodynamic instability, serious upper gastrointestinal hemorrhage and vomiting, and respiratory tract obstruction with secretions.

Data analysis

The changes of clinical symptoms and arterial blood gas were measured. The hemodynamic parameters such as heart rate, blood pressure, rate-pressure product were detected before and after BiPAP ventilation. Rate-pressure product (RPP) was calculated with the formula: RPP = heart rate × systolic pressure. Blood gas data were used to determine alveolar-arterial oxygen gradients ($A\text{-}aDO_2$).[7] Inspired oxygen fraction (FiO_2) was estimated in patients receiving liter flow oxygen by the following formula: FiO_2 equals 0.2 plus (O_2 flow [LPM] times.04).[8,9] Similarly, PaO_2/FiO_2 was calculated. Mild to moderate hypoxemic respiratory insufficiency was defined as an $A\text{-}aDO_2$ greater than 100 mmHg or PaO_2/FiO_2 ratio less than 200 mmHg. Severe hypoxemic respiratory insufficiency was defined as an $A\text{-}aDO_2$ greater than 250 mmHg or $PaO_2/$

FiO_2 ratio less than 100 mmHg.[10]

Data were expressed as mean ± standard error of the mean, or median if the data were skewed. Statistical analysis was performed using paired two-tailed *t* test to compare clinical and laboratory variables before and after initiation of nasal mask BiPAP ventilation. A *P* value less than 0.05 was considered significant.

Results

The 25 patients experienced 30 episodes of respiratory insufficiency and required airway support or oxygenation/ventilatory support. They were treated with BiPAP ventilation without major complications. The episodes presented with hypoxemia in all patients, 9 of whom had hypercapnia at the same time. Twenty-five episodes (83.3%) benefited from BiPAP and avoided re-intubation. Five episodes in 4 patients led to progression of respiratory failure and were subsequently treated with an artificial airway. Of the 4 patients, 3 received BiPAP twice and avoided re-intubation again, and 1 patient received nasal mask BiPAP ventilation for 3 times; it was successful for the third time. All patients were discharged from the hospital after a mean mechanical ventilation duration of 3.4 days (range, 0.2-14.6 days) and ICU stay of 10.6 days (range, 4-41 days).

Table 1. Patients characteristics

Sex		Age (y)	Disease	Time (d)		Time (h)	Outcomes
				MV	BiPAP	Interval from MV to BiPAP	
1	M	0.25	VSD+ASD	1.83	1.25	6	Survived
2	M	0.67	VSD+PH	1.88	1.1	19	Survived
3	F	1.1	VSD+PH	0.2	0.77	22	Survived
4	F	0.5	AVSD	0.92	1.2	2	Survived
5	F	2	TOF	0.92	0.42	0.83	Survived
6	M	0.33	VSD+PH	1	1.3	2	Survived
7	M	0.92	TOF	5.59	1.7	7	Survived
8	M	6	TOF+PDA	10.9	4	1	Survived
9	F	0.92	TOF+ASD	1	4.83	72	Survived
10	M	1.2	CAVC	0.79	0.25	11	Survived
11	F	9	TGA+ASD+VSD+PS	1.8	0.9	1.75	Survived
12	F	0.58	VSD+PH	0.96	0.96	2	Survived
13	M	0.33	TOF	1.71	0.58	33	Survived
14	M	0.33	TOF	0.92	0.88	4	Survived
15	F	0.33	VSD+PH	0.92	0.03	0.67	Survived
16	F	1.5	Cor triatriatum+ASD	2.33	0.71	1	Survived
17	M	2	TOF	8.83	1.83	1.5	Survived
18	M	0.42	VSD+PH	0.96	0.25	5	Survived
19	F	7	TOF	0.88	0.83	0.5	Survived
20	M	11	VSD+ID+CHF+MR+TR	7	0.33	0	Survived
21	F	2.5	TOF	0.63	1.17	10	Survived
22	F	0.42	DORV+VSD+PH				
		first time		2	2	0.5	Reintubated
		second time		4	4	5	Survived
23	M	4.6	TOF				
		first time		2.62	0.21	24	Reintubated
		second time		2.5	1	0	Survived
24	F	1.5	TOF				
		first time		3.88	0.38	5	Reintubated
		second time		4.5	1.92	48	Survived
25	F	2.5	PA				
		first itme		2.79	2	0	Reintubated
		second time		2	10	0	Reintubated
		third time		9.8	12	0	Survived

BiPAP=bilevel positive airway pressure ventilation, MV=mechanical ventilation, TOF=Tetralogy of Fallot, PDA=patent ductus arteriosus, ASD=atrial septal defect, VSD=ventricular septal defect, PH=pulmonary hypertension, CAVC=complete atrioventricular canal, TGA=transposition of great arteries, PS=pulmonary stenosis, DORV= double outlet right ventricle, PA=pulmonary atresia, ID=infective endocarditis, CHF=chronic heart failure, MR=mitral regurgitation, TR=tricuspid regurgitation.

Patients received BiPAP for 9.4 hours (range, 0-72 hours) after extubation, with a mean duration of 1.96 days (range, 0.03-12 days). As the S/T mode was adopted, IPAP was 9.6 (range, 7-15) cmH_2O, EPAP was 4.9 (range, 4-7) cmH_2O, and breath rate was set at 11.8 (range, 5-25) beats/minute. The patients were given sedatives for a mean of 1.7 (range, 1-4) times per day. Complications such as pneumothorax, abdominal distention, and aspiration were not seen. Two patients showed irritation of facial skin. All patients were fed through a nasogastric tube during BiPAP ventilation.

One hour after institution of BiPAP, the patients showed marked improvement of oxygenation. pH increased from 7.37±0.02 to 7.41±0.01, SaO_2 increased from 93.8±1.0% to 97.7±0.4%, PaO_2/FiO_2 increased from 189.9±25.0 to 253.6±21.2 mmHg, $A\text{-}aDO_2$ decreased from 241.8±18.7 to 182.1±16.5 mmHg (all $P<0.05$). At 4 hours after institution of BiPAP, $PaCO_2$ significantly decreased from 44.0±2.1 to 38.9±0.8 mmHg ($P<0.05$) (Table 2).

Meanwhile, the patients showed a marked improvement of clinical symptoms. Heart rate decreased from 157±4 to 139±4 beats/minute, respiratory rate from 46 ±2 to 37±2 breaths/minute, rate-pressure product from 17 230±685 to 14 046±423 mmHg · beats/minute (all $P<0.05$) (Table 3).

Discussion

Post-extubation respiratory insufficiency is commonly seen in children after cardiac surgery, especially in those with complex congenital heart disease. Patients may present with pneumonia, pulmonary edema, bleeding, alveolar collapse, and atelectasis after cardiopulmonary bypass. In our study, the patients with respiratory insufficiency after cardiac surgery tolerated BiPAP ventilation with improved respiratory distress, decreased respiratory rates, and improved blood gas exchange. Clinical response was associated with improvement of oxygenation.[11]

With no invasive artificial airway and fewer complications, noninvasive positive pressure ventilation (NIPPV) is superior to invasive ventilation. Similarly in invasive ventilation, NIPPV provides effective respiratory support by improving ventilation and decreasing the work of breathing.[12] With the use of NIPPV, new modes are emerging. Nasal mask BiPAP ventilation is more advantageous than noninvasive continuous positive pressure ventilation.[13,14] BiPAP ventilation for delivery of inspiratory pressure has been shown to markedly reduce the work of breathing. The flow-triggered bilevel system can decrease expiratory work of breathing and improve patient comfort. The BiPAP ventilatory support system offers a backup ventilator mode for machine breath in the event of apnea.

Table 2. Blood gas and calculated indices of oxygenation before and after institution of noninvasive bilevel positive pressure support ventilation

	pH	$PaCO_2$ (mmHg)	PaO_2 (mmHg)	$A\text{-}aDO_2$ (mmHg)	PaO_2/FiO_2 (mmHg)	SaO_2 (%)
0 h	7.37±0.02	44.0±2.1	104.2±13.8	241.8±18.7	189.9±25.0	93.8±1.0
1 h	7.41±0.01*	40.6±1.2	122.5±9.1	182.1±16.5*	253.6±21.2*	97.7±0.4*
4 h	7.42±0.01*	38.9±0.8*	133.3±12.3	179.5±16.7*	266.8±25.4*	97.8±0.4*
8 h	7.43±0.01*	37.8±0.8*	139.4±11.0*	166.6±18.4*	292.4±25.8*	98.1±0.4*
24 h	7.42±0.01*	39.6±1.0*	145.8±12.2*	151.3±17.9*	309.2±26.4*	98.1±0.5*
48 h	7.43±0.01*	40.4±1.2	151.9±10.8*	111.0±18.1*	361.2±27.3*	98.5±0.3*
72 h	7.42±0.01*	39.9±1.4*	147.8±8.5*	81.3±16.2*	396.2±23.4*	98.8±0.2*
End	7.44±0.01*	39.5±1.1*	158.4±11.8*	127.8±16.3*	344.4±26.3*	98.7±0.2*

Data were expressed as mean ± standard error of the mean; compared with 0 h, *: $P<0.05$.

Table 3. Clinical variables before and after institution of noninvasive bilevel positive pressure support ventilation

	Heart rate (beats/minute)	Respiratory rate (beats/minute)	Arterial systolic pressure (mmHg)	Rate-pressure product (mmHg · beats/minute)
0 h	157±4	46±2	109±3	17230±685
1 h	139±4*	37±2*	102±3*	14046±423*
4 h	137±4*	37±2*	99±2*	13570±433*
8 h	134±5*	36±2*	96±2*	12822±406*
24 h	136±4*	37±2*	99±2*	13322±423*
48 h	135±3*	35±2*	98±2*	13286±472*
72 h	131±3*	32±2*	93±2*	12217±409*
End	139±3*	36±2*	96±2*	13399±426*

Data were expressed as mean ± standard error of the mean; compared with 0 h, *: $P<0.05$.

Improving ventilation by BiPAP in patients with acute respiratory insufficiency after cardiac surgery is mainly associated with the reduced work of breathing and alleviated the respiratory muscle fatigue.[11,15] The improved conditions of some of our patients were due to the support for respiratory muscles or "stenting" of the upper airway or large bronchi. This mechanism contributed to the reduction of hypercarbia in our patients with mask ventilation. Many of these patients may also have underlying acquired neuromuscular deficits related to critical illness or prolonged use of neuromuscular blockade, by which positive pressure delivery after extubation could improve minute ventilation. It was reported that BiPAP not only resulted in enhancing oxygen delivery, but also in increasing myocardial contractility, decreasing preload and afterload of the left ventricle, and alleviating pulmonary edema.[3] Patients in this study may be benefited from the optimized cardiopulmonary interaction as well.

The understanding of appropriate indications for BiPAP ventilation is a prerequisite for the success. In this study, BiPAP was most effective in patients with respiratory muscle fatigue and without respiratory tract obstruction, and in those whose dyspnea were considered to be transient and relieved soon with further therapy. BiPAP ventilation should be considered in the patients clinically judged to be in early acute respiratory distress who would otherwise require an artificial airway for support of gas exchange. Failures of BiPAP ventilation were characterized by a progressive increase in the work of breathing and further derangement in gas exchange despite initiation of BiPAP ventilation.[16] Assessing the treatment failures of the five episodes, we concluded that BiPAP ventilation did not promote the progression of the underlying disease process, because progressive derangement in gas exchange was seen even after we resorted to intubation and ventilation.

We routinely extubated the patients after cardiac surgery as early as possible, if they were hemodynamically stable only. Otherwise, prolonged mechanical ventilation had to be used for the patients with severe underlying disease. These patients were so critically ill that they often developed respiratory insufficiency after weaning from the ventilator and required re-intubation. We strongly recommend the use of noninvasive nasal mask BiPAP ventilation as an alternative strategy to invasive airway support in patients with prolonged mechanical ventilation, especially those who are dependent on airway support and difficult to be weaned from the ventilator.[17,18] In this study, 4 patients had difficulties in weaning from the ventilator. Among them, 3 patients receiving BiPAP twice were successfully treated without re-intubation at the second time, and 1 patient receiving BiPAP for 3 times (with duration of 2, 10, and 12 days, respectively) was discharged with an ICU stay of 41 days.

Reported complications related to BiPAP ventilation use are the potential for abdominal distention or aspiration[19] and the pressure sores over the nasal bridge.[20] Only 2 patients showed irritation of the facial skin in our study. There was no failure of BiPAP ventilation because of BiPAP related complications.

Optimizing respiratory care in children after cardiac surgery effectively may decrease morbidity and mortality. BiPAP ventilation is of potential benefit in critically ill pediatric patients with acute respiratory distress after cardiac surgery, avoiding intubation. BiPAP ventilation can result in marked decrease in heart rate, respiratory rate, and improvement in gas exchange. BiPAP ventilation can prevent the translaryngeal, physical, and psychological trauma that can occur with intubation or long-term tracheostomy. Experienced staff must be available and surveillance must be maintained, so that endotracheal intubation can be performed if the patient's condition deteriorates and intubation is required.

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