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The effect of variations in positive end expiratory pressure on gas exchange in ventilated children with liver disease

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Abstract. The effect of varying the positive end expiratory pressure (PEEP) level during mechanical ventilation has been assessed in ten children with liver disease, mean age 3.8 years. PEEP was increased 3 cmH_2O above the child's original (baseline) PEEP level and then decreased either by 3 cmH_2O below the baseline or to 0 cmH_2O. In all ten children increasing the PEEP above the baseline improved oxygenation; in the group overall the median PaO_2 increased from 90 mmHg to 97 mm Hg ($P < 0.01$). In eight of the ten children decreasing the PEEP level below the baseline resulted in a deterioration in oxygenation; in the group overall the median PaO_2 decreased from 91 mmHg to 82 mmHg ($P < 0.05$). Changes in PEEP levels, however, did not result in clinically significant alterations in $PaCO_2$, heart rate or blood pressure. We conclude that modest increases in PEEP are well tolerated in children with liver disease and result in an improvement in oxygenation.

Key words: Mechanical ventilation – Paediatric intensive care – Positive end expiratory pressure

Introduction

Positive end expiratory pressure (PEEP) has been used during mechanical ventilation for more than 20 years in both adult [1] and neonatal practice [9]. Many studies have investigated the possible benefits and disadvantages of PEEP in those groups, but very little data have been obtained in children. As a consequence, recommended [10] policies regarding optimum PEEP levels for use in children have been extrapolated from the results of trials in adults and neonates. This practice, however, may not be appropriate as both the lung physiology and spectrum of disease in the paediatric population differ from either of the other two groups. The aim of this study, therefore, was to study the effects of a series of PEEP levels in children with liver disease being mechanically ventilated.

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Abbreviations: FRC = functional residual capacity; PEEP = positive end expiratory pressure

Methods

Children with liver disease admitted to the intensive care unit at King's College Hospital were eligible for entry into the study. Patients were recruited into the study once haemodynamically stable and when their blood gases had been within the desired range (pH 7.3–7.5, PO_2 65–100 mgHg, PCO_2 25–45 mmHg) for at least at 2 h period without any change in ventilator settings. All patient care (physiotherapy, turning etc.) was completed 15 min prior to the commencement of each study.

The children were initially studied at their original ventilator settings (baseline PEEP). PEEP was then decreased by 3 cmH_2O (low PEEP level). In children whose baseline PEEP was less than 3 cmH_2O the PEEP level was reduced to 0 cmH_2O. The level was subsequently increased to 3 cmH_2O above baseline (high PEEP level). After each change to a new PEEP level the child was returned to the baseline PEEP. The patient remained at each setting for 20 min. During the study period no change was made in the other ventilator settings.

All patients had indwelling arterial catheters which has been sited for clinical purposes. From these lines arterial blood gases were sampled after each 20 min period and analysed immediately. Heart rate and blood pressure were continuously displayed by a bedside monitor (Horizon-Viamed, Keighley, UK). The mean heart rate, systolic and diastolic pressures over a 20 s period at the end of each 20 min period were recorded.

Analysis

The PaO_2 and $PaCO_2$ at the three periods at the baseline PEEP were compared, as were the PaO_2 and $PaCO_2$ at the high or low level of PEEP to that achieved at the immediately preceding baseline PEEP level. Differences were assessed for statistical significance using the paired Wilcoxon signed rank sum test. Changes in PaO_2 from increasing or decreasing PEEP were related to the baseline PEEP and inspired oxygen concentration. To assess statistical significance Sperman's correlation coefficients were calculated.

Trial size

Recruitment of ten children gave us the ability to detect with 90% power at the 5% level a difference of 8 mmHg in PaO_2 and 6 mm Hg

Table 1. Patient characteristics

Patient	Age (years)	Diagnosis	Paralyzed	PIP	PEEP	FiO_2	Rate	I:E
1	0.3	Fulminant hepatic failure	Yes	18	2	21	20	1:5
2	0.5	Post liver transplant	Yes	29	5	88	35	1:2
3	1.1	Post liver transplant Septicaemia	Yes	40	6	40	20	1:2
4	2.4	Post liver transplant	No	29	3	28	19	1:2
5	2.5	Hepatocellular failure Pneumococcal sepsis	Yes	28	3	33	16	1:3
6	4.8	Post liver transplant	No	26	5	30	22	1:2
7	9.8	Hepatocellular failure	No	32	3	30	16	1:3
8	10.1	Hepatocellular failure Typhoid	No	22	4	30	25	1:2
9	10.9	Post liver transplant	No	24	2	40	16	1:3
10	12.0	Extrahepatic biliary atresia Portal hypertension	Yes	30	5	79	20	1:2

in $PaCO_2$ between PEEP levels, based on a variability of ±5 mmHg in PaO_2 and ±4 mmHg in $PaCO_2$.

Patients

Ten children were recruited into the study, all suffered from liver disease (Table 1) and none had a primary pulmonary disorder. Their median age was 3.8 years with a range of 3 months to 12 years (Table 1). The children were all ventilated by volume controlled ventilators. Their inspired oxygen concentrations ranged from 21% to 88% and PEEP from 2 to 6 cm H_2O (Table 1). All patient had uncuffed endotracheal tubes. Five were paralysed and all the patients were sedated with either fentanyl or propofol throughout the study (Table 1).

The study was approved by the King's College Hospital Ethics Committee.

Results

The mean oxygen levels during the periods at the baseline PEEP did not vary significantly (Fig. 1). There was a fall in the oxygen tension in eight patients, but an increase in two patients (patients 3 and 10 of 1 mmHg and 7 mmHg respectively), when PEEP was reduced from the baseline to the low level. In the group overall the PaO_2 decreased from a median of 91 mmHg (range 60–99) at the baseline to a median of 82 mmHg (range 56–105) at the lower PEEP level ($P < 0.05$). All patients showed an improvement in PaO_2 as the PEEP level was

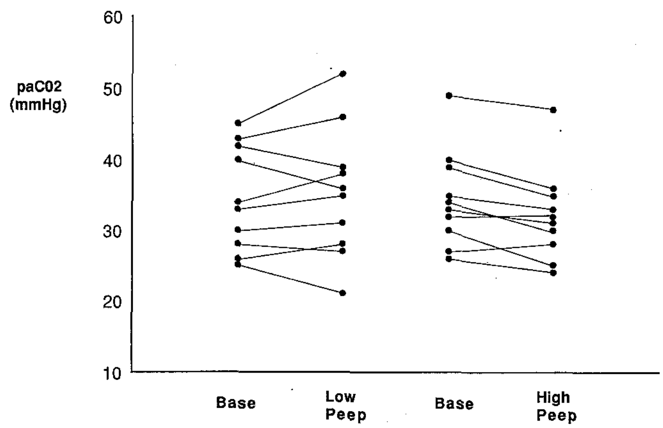

Fig. 2. $PaCO_2$ levels (mmHg) with variations in PEEP. Linked data points represent an individual's results

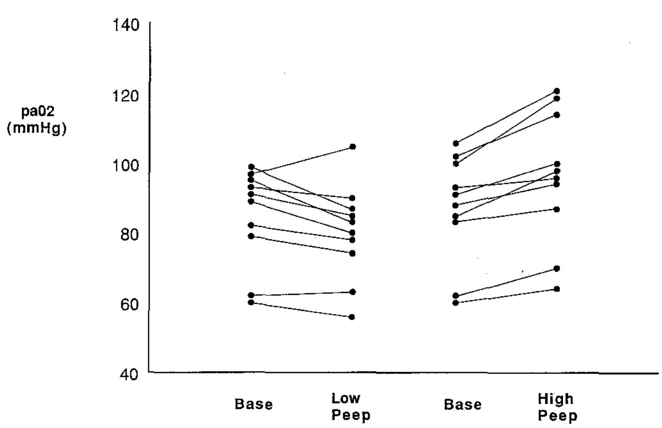

Fig. 1. PaO_2 levels (mmHg) with variations in PEEP. Linked data points represent an individual's results

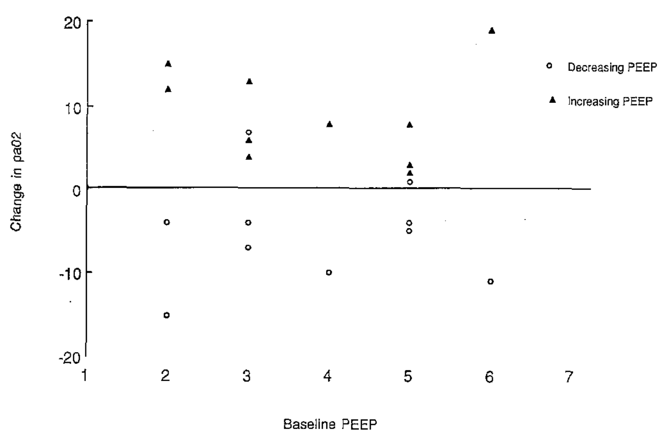

Fig. 3. Changes in PaO_2 (mmHg) obtained on increasing or decreasing PEEP. Individual data are demonstrated, each child's data point is plotted according to his or her baseline PEEP (cmH_2O)

increased to the high level. The median PaO_2 at the baseline level was 90 mm Hg (range 61–106) and 97 mm Hg (64–121) at the higher PEEP level ($P < 0.01$). The mean carbon dioxide levels during the periods at the baseline PEEP did not vary significantly (Fig. 2). The only significant change in $PaCO_2$ levels was on increasing the PEEP from baseline to the higher level, at baseline the median $PaCO_2$ was 32 mm Hg (mean 34, range 26–49) and at the higher level 32 mm Hg (mean 32, range 24–47) ($P < 0.05$). No significant relationship was found between the baseline PEEP level (Fig. 3) and the change in PaO_2 on decreasing or increasing the PEEP from the baseline.

No significant effect on heart rate or blood pressure resulted from increasing or decreasing the PEEP level. Throughout the study in no patient did the heart rate vary by more than 15 beats min or the systolic or diastolic blood pressure by more than 10 mmHg.

Discussion

We recruited only children with liver disease into this study, as we hoped the results would facilitate recommendations regarding PEEP levels in a specific patient population. The data demonstrate that in all the patients increasing PEEP from baseline to the higher level improved oxygenation. Our findings are consistent with those obtained from studies in adults [11] and neonates with respiratory failure [2]. In baboons, this improvement in oxygenation has been associated with an increase in functional residual capacity (FRC) [6]. In both adults [11] and neonates [3, 5], the effect of increasing PEEP is determined by the level achieved. If a certain level is exceeded ventilation may worsen [5, 11] and lung function deteriorate [3]. This PEEP level in neonates depends on the type of lung disease [3] and appears inversely proportional to the baseline FRC [11]. Our study patients were relatively heterogeneous in that they had a wide age range, but they all suffered from severe hepatic disease as evidenced by their need for transplantation or that they were in hepatic failure. We have previously found patients with severe liver disease to have a low FRC [4] and felt their low lung volume was likely to be explained by compression due to hepatosplenomegaly and ascites [4]. In addition, amongst children with a wide range of severity of liver disease, we have noted [7] little evidence of obstructive airways disease, as indicated by a lack of bronchodilator responsiveness. Thus, increasing PEEP levels in such patients may have improved oxygenation by an increase in FRC.

We did not randomize the order in which the changes in PEEP level were applied. After each new PEEP level, however, the patients were always returned to the baseline level for 20 min to prevent any "hang-over" effect. We felt this had been achieved as there was no significant difference in the PaO_2 (Fig. 1) or $PaCO_2$ (Fig. 2) at the three baseline levels.

The only significant change in $PaCO_2$ was on increasing PEEP from the baseline to the higher PEEP level, but this change was modest (Fig. 2), a median decrease in $PaCO_2$ of 2 mmHg (range −5 mmHg to +1 mmHg) and thus not likely to be of any clinical significance. We therefore feel that in our study population, increasing PEEP improved lung function without causing overdistension, hence increasing oxygenation without significantly impairing CO_2 elimination. Although all our patients suffered from hepatic disease, they had a wide age range and varied ventilatory requirements prior to commencing the study, yet all responded in the same manner to an elevation of PEEP. This suggests the results may be applicable to children with other diseases which are associated with low volume, noncompliant lungs.

Our data argue, in children who have no evidence of obstructive airway disease, for a trial of higher levels of PEEP than are currently being used in neonates with acute respiratory failure [3, 5], particularly as we found no adverse effects on CO_2, heart rate or blood pressure on increasing PEEP. We have, however, no data to substantiate the use of very high levels of PEEP [8, 12] which have been noted to result in marked physiological disturbance in adults [12].

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