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Case report

Initial optimal continuous distension pressure in prone HFOV in a paediatric burn: case report

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1. Introduction

One of the main reasons why use of high frequency oscillatory ventilation (HFOV) in paediatrics and adults is extensively studied is the possible introduction of this ventilatory mode as an effective lung-protective approach in treatment of ARDS. The strong rationale for the use of HFOV is based on the generation of a stable lung volume guaranteed by the level of continuous distension pressure (CDP) throughout the proximal and distal airways and by small pressure–volume fluctuations on the alveolar level. The results of multicentre studies in recent years contributed to solving the problems of identifying a target group and strategy of HFOV [1–3]. An important component of the clinical and experimental protocols is also the testing of methods improving oxygenation, in particular prone position and inhaled nitric oxide (NO) [4–6].

The Department of Anaesthesiology and Critical Care of Charles University Hospital has been engaged in a study of high frequency oscillatory ventilation in adult patients since 1999. In addition to 25 adult patients, this method has been successfully used on two children. One of them was a 13-month-old child with serious burns. According to the available data, from 1995 until 2001, 675 children with serious burns have been admitted to the Burns Centre (BC), 73 of them required a ventilatory support during the treatment. ARDS developed in only six cases. Three of them were patients with scalds, one was injured by an electric current and in the other two cases the injuries were caused by a flame burn. All these injuries involved 57 ± 24% of the body surface area. Recent literature focusing on the use of HFOV in the treatment of ARDS in severely burns contains studies supporting further exploration of this approach in combination with the adjunct methods of oxygenation improvement [7–9].

This report presents the case of a previously unreported successful use of HFOV initiated in prone position in the severely burnt child affected by ARDS, which has given interesting data for discussing the pending questions of HFOV treatment, particularly the adjustment of timing of suitable prone–supine periods, recruitment manoeuvres, continuous distension pressure changes, and HFOV weaning parameters.

2. Case report

A 13-month-old boy was scalded with hot tea involving 35% of his body surface area (TBSA grade IIa–b). The burns were localised on the face, neck, front and back part of the trunk and both upper extremities. At the time of the injury, an intraoseal access was ensured in the tuberositas tibiae area with a consecutive infusion of full Ringer's solution. Because of localisation and the extent of the scald, an orotracheal intubation was used to secure the patency of the airways and artificial lung ventilation was started. The wounds were covered with a sterile dressing. From the place of the primary treatment the patient was transported by ambulance to the BC, where he was admitted 2 h after the injury. During the transport, the analgesia was provided by the bolus dose of 50 micrograms of fentanyl and 2 mg of midazolam with parallel continuous administration of Ringer's solution. In

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the Admissions Theatre of the BC the burnt surface was treated with xenotransplantation. After the initial treatment the patient was transferred to the paediatric intensive care unit. Results of the laboratory tests at the time of admission displayed a hyponatraemia (134 mmol/l), hypokalaemia (3.33 mmol/l), lower total protein (53 g/l) and slight elevation of aminotransferases (ALT $=$ 51 IU/l, AST $=$ 71.4 IU/l). A slight hyperglycaemia (6.96 mmol/l) was followed by hypoglycaemia (2.5 mmol/l) consequently treated by administering 20% glucose solution. The haemoglobin was 148 g/l, HTC 44.5%, erythrocytes 6.05×10^{12}/l, leucocytosis 30.7×10^{9}/l and platelet count 310×10^{9}/l. No signs of an inhalation injury were present. A daily supply of fluids and electrolytes was administered according to a modified Brook's formula. For the first 24 h 2000 ml of Ringer's solution was administered intravenously. Controlled mechanical ventilation was performed in a pattern of pressure-controlled and time-cycled ventilation, later followed by pressure-limited volume-controlled type (Servoventilator Siemens Elema 300C). A chest X-ray on the day of admission reported a shadow in the peri-hilar region on the right side. Antibiotics were not administered. Within the first 24 h a generalised burns oedema was increasing while the diuresis was adequate (2.5 ml/kg of BW/h) and the circulation was stable without the need of an inotropic support. The second day after the accident the hypoxaemic index decreased to 190 Torr. A chest X-ray showed a fluidothorax in the right and bilateral diffuse infiltrates, particularly in the right lower pulmonary field. During the third day after the injury, ventilation was set to fulfil the parameters of the protective ventilatory regimen: tidal volume $V_{\mathrm{T}} = 6$ ml/kg, ventilatory rate 45/min, positive end-expiratory pressure (PEEP) was increased from 0.8 to 1.6 kPa, and mean airway pressure (MAP) was increased from 1.1 to 2.4–2.6 kPa. In spite of that the peak inspiratory pressure (PIP) exceeded a level of 4 kPa. Partial tension of oxygen in the arterial blood reached 6.8 kPa while the inspiratory oxygen fraction was $\mathrm{F_IO_2} = 1$. Partial tension of CO_2 in the arterial blood increased to slightly hypercapnic values, $\mathrm{PaCO_2} = 7.6$ kPa. Recruitment manoeuvres led to a temporary and short-term improvement of oxygenation. The child was turned to the prone position. In the following 10-h period it was possible to decrease the oxygen fraction in the inspiratory mixture to 0.6 ($\mathrm{F_IO_2} = 0.6$). The change of position to the supine position after this time interval unfortunately led to a serious decrease of the arterial oxygen saturation. That is why the child was kept in the prone position for the next 12 h. His condition did not improve till the next morning when the chest X-ray examination confirmed a severe form of ARDS (Fig. 1) with a hypoxaemic index of 75 Torr and a permissive hypercapnia with $\mathrm{PaCO_2} = 7.14$ kPa. The decrease in the pH value to 7.14 indicated a progressive lactate acidosis. Diuresis was failing despite a pharmacological support.

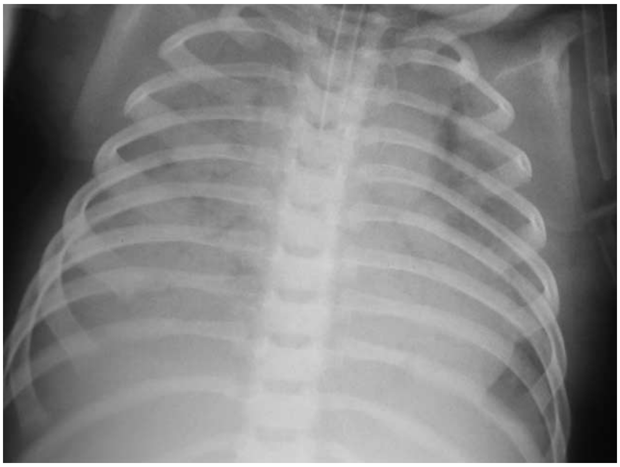

Fig. 1. Chest X-ray before HFOV introduction.

In this condition high frequency oscillatory ventilation in prone position was initiated. During a deep analgosedation and continual relaxation of the patient, the HFOV parameters were set according to the standard recommendation, i.e. initial continuous distension pressure 0.5 kPa above the mean airway pressure value during the conventional ventilation (CDP $=$ 3.1 kPa), continuous flow $=$ 20 l/min, relative inspiratory time $T_{\mathrm{I}}/T = 0.5$, pressure amplitude at the proximal end of the endotracheal tube $\Delta P = 10$ kPa, and ventilatory frequency $f = 10$ Hz. Looking for an optimal continuous distension pressure, the best oxygenation parameters were found at a surprisingly high CDP value of 4 kPa. The continuous distension pressure was well tolerated by the child. The circulatory conditions of the patient did not require any inoconstrictor support. Urine output increased to 87 ± 6 ml/h, but the support of diuresis by furosemide was still necessary at a level of 8 mg/kg BW per day. Within the first 12 h of the high frequency oscillatory ventilation in the prone position, the oxygenation parameters improved and gradually allowed the oxygen fraction to decrease to $\mathrm{F_IO_2} = 0.4$. After reaching a low inspiratory oxygen fraction ($\mathrm{F_IO_2} = 0.3$) relatively quickly, the CDP was kept at a high level due to the pulmonary instability monitored by the pulse oxymetry changes. During the first day of HFOV, it was necessary to keep the CDP level not lower then 3.7 kPa. A gradual step-by-step decrease of CDP by 0.2 kPa during the next 8 days was guided by the values of the arterial oxygen partial pressure, while switching prone/supine positions. The changes in the oxygenation index (OI), hypoxemic index and CDP in the course of the oscillatory ventilation are shown in Figs. 2–4. The changes of position (supine to prone or prone to supine) were decided on the basis of the oxygenation trend evaluation, which reflected the reaction to the recruitment manoeuvres, and the periodical testing of hyperinflation or hypoinflation. This was conducted by the transient increase or decrease of CDP and parallel analysis of $\mathrm{SpO_2}$ values. The level of optimal CDP in the prone position was identified repeatedly on a higher level compared to the supine position, which is in correlation with changes of the thoracic wall compliance.

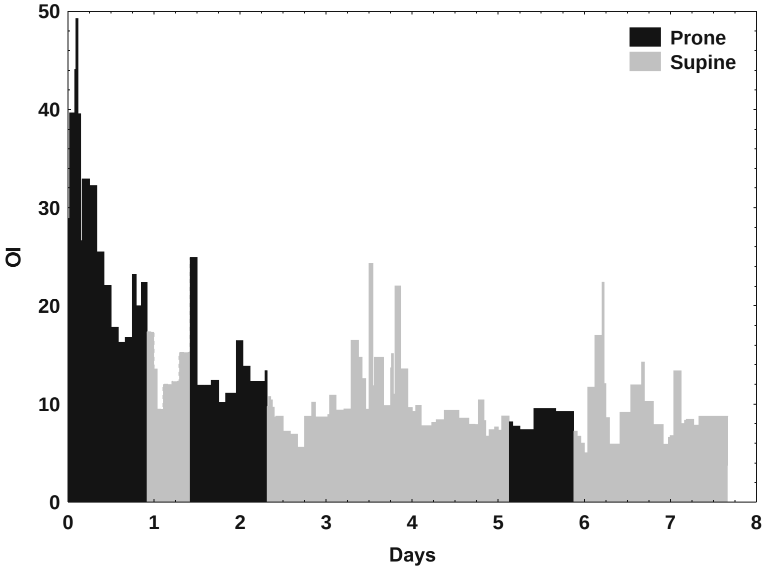

Fig. 2. Time development of oxygenation index.

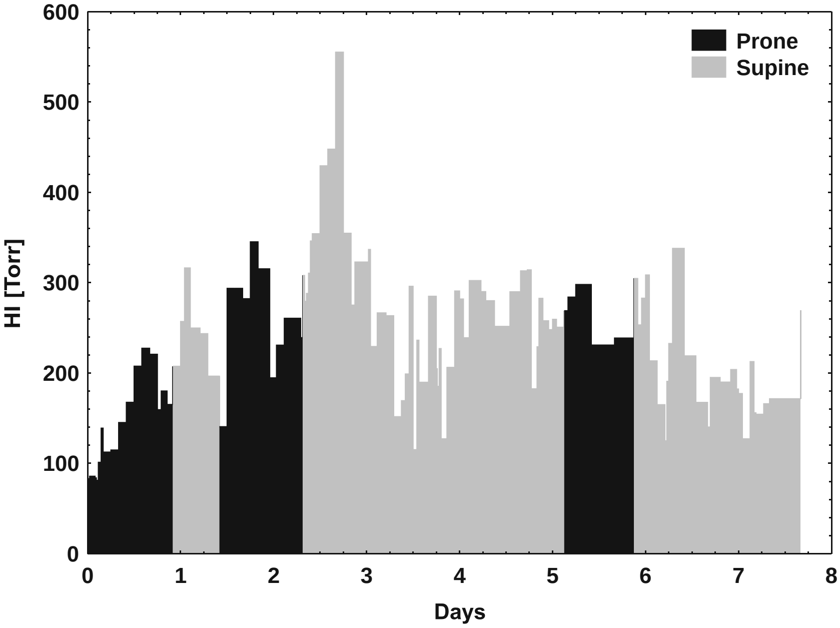

Fig. 3. Time development of hypoxemic index.

The generalised oedema was mobilised within the first week. The burns healed spontaneously without any surgical intervention.

The child was switched to conventional mechanical ventilation when CDP was 1.2 kPa. The starting parameters of the conventional volume-controlled ventilation were as follows: $F_IO_2 = 0.4$, PEEP $= 0.8$ kPa, $V_T = 6$ ml/kg, PIP $= 2$ kPa, $f = 45$/min and MAP $= 1.1$ kPa. The final successful extubation was performed after 11 days in order to prevent the opiate syndrome.

3. Discussion

The extraordinarily high, effective, CDP (CDP $=$ 4.0 kPa, oxygenation index OI $= 50$), used in the injured 13-month-old child, exceeded pressures recommended for so-called recruitment manoeuvres during conventional ventilation in adults. It was close to the recommended maximal CDP value of 4.5 kPa for adults. The effect of the rescue application of HFOV can be explained by the description of differences in pressure changes during conventional and

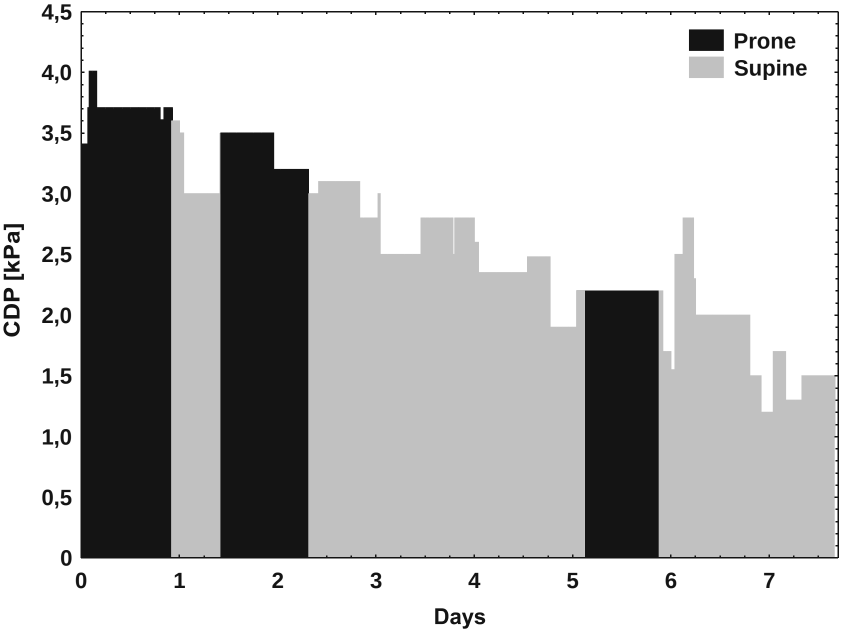

Fig. 4. Time development of continuous distension pressure.

high frequency oscillatory ventilation. During conventional ventilation there is enough time for the intrapulmonary pressure to equalise with the proximal pressure. So the proximal pressure amplitude (ΔP) is at the same time the amplitude of the alveolar pressure (ΔP_{alv}). The situation is completely different in HFOV. The alveolar pressure does not keep up with changes of the proximal pressure and the amplitude doesn't reach even 10% of the proximal pressure amplitude (ΔP) [11]. Nevertheless it can be higher in ARDS. The optimal distension in some forms of ARDS (perhaps in extrapulmonary ARDS) in conventional ventilation cannot be assured, because the pressure in the alveolar space at the end of expiration decreases to below a level sufficient for keeping the alveoli opened. It is the main cause of the collapse of distal lung compartments. The lungs can be reopened using either recruitment manoeuvres or consecutive "sighs" [10]. The situation is different in HFOV where the continuous distension pressure operates during the entire breathing cycle. This distension is particularly obvious in extrapulmonary forms of ARDS with outstandingly decreased chest wall compliance. A surprisingly good circulatory tolerance of the high continuous distension pressures used during HFOV could be explained by the increase of lung compliance and thoracic volume, caused by the CDP in extrapulmonary forms of ARDS. Recruitment using CDP, contrary to conventional ventilation, brings circulatory stability with a considerable decrease of the shunt. The trend of hypoxemic and oxygenation index during supine/prone position during HFOV (Figs. 2–4) clearly indicates the necessity of the position changing. The timing could be a parameter reflecting features of the lung lesion and could be of a different individual value. This should also be considered during conventional ventilation.

The courses of the oxygenation index curve and the hypoxemic index presented in this case report show distinctly that the fundamental improvement of oxygenation occurred during the first 12 h of HFOV. The continuous distension pressure had to be decreased gradually during 8 days. Solving of hypoxia in the short-term, which is not unique, but common mainly in extrapulmonary ARDS, could also give the possibility of not using the prone positioning as a part of the initial standard protocol for adult/paediatric severe ARDS, with the exception of starting HFOV in prone position. If HFOV is effective, based on our experience, the oxygenation problems could be solved within 12, or maximally 24 h. If the situation does not lead to a substantial improvement in oxygenation, conventional ventilation with the use of the adjunct oxygenation improving methods, including the prone position and the inhaled nitric oxide, should be considered.

Another peculiarity of the case of the burnt child was that, although the patient was in a general oedema for a few days, the burnt wounds healed completely without any need of surgical intervention.

4. Conclusion

High frequency oscillatory ventilation, combined with prone/supine positioning, could be an effective method of treatment in serious forms of extrapulmonary ARDS. Initial continuous distension pressure in peak initial values in children can reach a value close to the highest recommended level for adults. The advantage of HFOV, compared to the conventional ventilation, is the possibility of exact optimal continuous distension pressure titration guided by the oxygenation gain and a better cardiovascular tolerance of the method in extrapulmonary ARDS. The prone and supine position changes and the continuous distension pressure decrease are necessary to be assured according to the oxygenation trend and reactions to the recruitment manoeuvres based on a patient's individual reaction. Further clinical research is required to study the use of HFOV in the prone and supine positions in severe ARDS in adults and children.

Acknowledgements

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