Atelectasis is defined as a collapsed and non-aerated region of the lung parenchyma. When persistent, atelectasis may worsen into bronchopulmonary infection. In addition, atelectasis may occur especially in younger children because of a mechanical predisposition to alveoli collapse. Atelectasis has no gold standard treatment and varies depending on duration and severity of the causal disease. The prevalence of this disorder is not well documented in non-ventilated patients. Several chest physiotherapy techniques (CPT) aim to reduce atelectasis by homogenisation of the spontaneous ventilation. Strategies of these methods are widely described and reviewed. CPT is, however, not part of the Vietnamese physiotherapist’s education. Local therapists generally learn respiratory rehabilitation from their own experience in the field. From 1996 the collaboration with the group Amphore (http://www.amphore.org) aims to improve knowledge and expertise of Vietnamese physiotherapists. A decade later, local physiotherapists now assure CPT for children themselves. The Paediatric Hospital no. 1 in Ho Chi Minh, Vietnam, organises the medical care support of 1500 paediatric inpatients and 250 paediatric outpatients. Almost 120 ambulatory children are referred every day for CPT. In this hospital, when respiratory infections are a complication, conventional CPT is often assessed as useless. In collaboration with Amphore, intrapulmonary percussive ventilation (IPV) was initiated from 1999. IPV is described as a promising technique in CPT. It seems to help in recovery from pulmonary infiltrates and atelectasis, with the big advantage of not requiring any voluntary participation from the patient. Few data support the use of IPV with patients other

Original Article

Atelectatic children treated with intrapulmonary percussive ventilation via a face mask: Clinical trial and literature overview

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Abstract

Background: Persistent atelectasis in children is lacking a gold standard treatment. Intrapulmonary percussive ventilation (IPV) is presented as a promising chest physiotherapy technique in the treatment of atelectasis. This study aimed to follow the evolution of atelectasis resolution with noninvasive IPV in young children and to detect eventual adverse effects.

Methods: Six children were hospitalized for respiratory distress with suspicion of atelectasis. A 15 min IPV treatment was immediately started at D1 twice a day for 5 days. Children were free of any other treatment. Chest X-Ray (CXR) was performed on the second day (D2) and was repeated 3 days later (D5). After the study, CXR were retrospectively reviewed by three specialists who had no knowledge of the clinical observations of the patients. They were asked to assess atelectasis by a score between 4 (complete collapse) and 0 (complete resolution). A clinical score on a maximum of 4 points was assessed by appetite deterioration, dyspnoea, mucus production and cough presence at D1 and D5 (1 point per symptom present). Paired t-test compared D1 and D5 results.

Results: All patients returned home after 5 days IPV. SpO2 normalized (93.2 ± 0.8 to 95.3 ± 0.8; P = 0.002) and patients all improved clinically (score, 2.8 ± 0.9 to 0.8 ± 0.6; P < 0.05). Out of four patients with radiographic evidence of atelectasis, three improved their atelectasis score.

Conclusions: No side-effect or adverse effect was observed during IPV treatments. IPV was safe and effective in atelectasis resolution in 3/4 of the cases. Patients all recovered a stable clinical state. CXR improved in 4/5 children. They were all discharged home after 5 days of IPV treatment.

Key words atelectasis, chest physiotherapy, intrapulmonary percussive ventilation, paediatric.
than cystic fibrosis\textsuperscript{8–13} or neuromuscular children\textsuperscript{14–16} or with patients out of an intensive care unit setting.\textsuperscript{17–21} We present here the results of a study with (IPV) as a treatment in children with suspicion of atelectasis. In this population, IPV was initiated after spontaneous respiratory deterioration at home.

Methods

Population

From 1–31 March 2005, 16 dyspnoeic patients referred to the Ambulatory Centre for Physiotherapy, Paediatric Hospital no. 1, Ho Chi Minh, Vietnam, were immediately hospitalized since they were judged unstable. Inclusion criteria of the present prospective uncontrolled observational study were: aged under 8 years, suspicion of atelectasis accompanied by respiratory distress, and arterial pulse oxymetry (SpO2) under 94%. Absence of any treatment such as CPT or medication before inclusion date was required. Fever was not an inclusion criterion since it is not clearly associated with atelectasis.\textsuperscript{22} Exclusion criteria consisted in the presence of a chronic respiratory disease based on chest X-ray (CXR) and on the interview of the patients’ parents (asthma, gastroesophageal reflux, ineffective cough due to neurological disorder or cystic fibrosis, which is absent in Vietnam). Enlarged heart that could compress lower bronchi or surrounding compressive nodules resulting from earlier tuberculosis were not exclusion criteria.\textsuperscript{23} From the 16 unstable children referred to the Ambulatory Centre of Physiotherapy in March 2005, only six met the inclusion criteria. The two main reasons for exclusion were the lack of evidence of atelectasis (\( n = 8 \)) and the difficulty in lung radiograph interpretation for unexpected technical reasons (\( n = 2 \)). Informed consent was obtained from the families of the participants and the study was approved by the Ethics Committee of Paediatric Hospital No. 1.

Material

The portable IPV (Impulsator, Percussionaire, Sandpoint, ID, USA) was used for the treatment through a face mask interface (Fig. 2). IPV device and variables were recently fully described.\textsuperscript{14,17} IPV ventilator delivers mini bursts of high velocity airflow providing peaks of pressure into the lungs (Fig. 3). This results in oscillatory positive pressure in the airways (Fig. 3a). As described in Figure 3, IPV positive pressure signal is not synchronized with the patient’s spontaneous breathing but superimposes on it. When patients breathe in, intra-thoracic negative pressure created by diaphragm contraction reduces the effect of the positive pressure provided by the IPV device (Fig. 3b). In contrast, when patients breathe out, the positive pressure created by the expiratory muscles adds to the positive pressure from the IPV display (Fig. 3c). By this mechanism, the highest peaks of pressure are reached at the beginning of the expiratory phase (Fig. 3; C1) and are followed by a steady state positive pressure during the expiratory apnoea phase of the spontaneous respiration (Fig. 3; C2). Those peaks of pressure create the percussive effect. The latter is likely to break up mucus plugging resistances and to enhance deep and homogeneous ventilation of the lungs.\textsuperscript{14} In the present study, parameters were selected with a frequency

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Intrapulmonary percussive ventilation (IPV). This model is a portable pneumatic IPV device; type Impulsator. It includes an internal compressor.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{Child undergoing intrapulmonary percussive ventilation through a face mask in a lying position.}
\end{figure}
between 150 and 220 cycles/min and with a fixed inspiratory/expiratory ratio at 1/1 at a pressure from 0.5 to 1 KPa. Patients were placed in a lying position and could breathe at their own respiratory rate. As in other continuous positive airway pressure techniques, patients were allowed to breathe normally and to superimpose their own spontaneous respiration naturally on the pressure generated by IPV (Fig. 3: B,C).14 IPV was carried out during 15 min twice a day in association with a medication-free water humidification included in the device.

Protocol

Patients were hospitalized and included at day 1 (D1). Oxygen pulse oximetry was measured at the beginning (D1) and at the end (D5) of the 5-day trial for each subject. Since patients were dyspnoeic and presented SpO2 ≤94%, IPV was immediately started for a 5-day trial. On the second day (D2), CXR was performed since clinical instability was confirmed. A second CXR was done on D5. In order to document the diagnosis of atelectasis, CXR was performed from both anterior–posterior and lateral projection.5 Because therapeutic decision from interpretation of paediatric chest radiographs is discussed in the literature, one paediatric pulmonologist and two radiologists without knowledge of the patients’ clinical diagnoses were asked to review and comment on the CXR retrospectively.24–25 Atelectasis severity was assessed by atelectasis score (AS) from 4 (complete collapse) to 0 (complete resolution).18 Finally, a clinical score on a maximum of 4 points was assessed at D1 and D5 by appetite deterioration, dyspnoea, mucus production and cough presence; one point was given per symptom present. We did not mix any other CPT technique like lateral positioning technique,5 chest clapping and vibration,18 high frequency chest wall compression,11,18 incentive spirometry16 or medication nebulisation13 in addition to IPV or to compare with IPV. Our study aimed to assess the effect of IPV on a very selected and homogeneous population. The limited number of patients did not allow us to compare with a control group treated with another CPT technique. Second, we could not compare the atelectatic severity from the study period to earlier CXR. For these reasons, we cannot exclude that radiological atelectatic evidence was already present before the study started. So, conclusion must be taken with prudence.

Statistics

Paired t-test compared D1 and D5 data. Significance was accepted for a P-value under 0.05.

Results

Demographics are presented in Table 1. The mean age was 36 ± 24 months (range, 1–84 months) and the weight was 12 ± 4 kg (range, 4–19 kg). After CXR reviewing without knowledge of

<table>
<thead>
<tr>
<th>n</th>
<th>Age (months)</th>
<th>Weight (kg)</th>
<th>Symptoms</th>
<th>TOTAL /4pts</th>
<th>SpO2 (%)</th>
<th>Symptoms</th>
<th>TOTAL /4pts</th>
<th>SpO2 (%)</th>
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<tbody>
<tr>
<td>1</td>
<td>24</td>
<td>10</td>
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<td>0 0 0 95</td>
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<tr>
<td>Mean</td>
<td>36,0</td>
<td>12,0</td>
<td>0,5 1,0 0,8 0,5</td>
<td>2,8 93,2 0,2</td>
<td>0,0 0,2 0,5 0,8</td>
<td>95,3**</td>
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<tr>
<td>SD</td>
<td>24,0</td>
<td>4,0</td>
<td>0,5 0,0 0,3 0,5</td>
<td>0,9 0,8 0,3</td>
<td>0,0 0,3 0,5 0,6</td>
<td>0,8</td>
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Paired t-test (day 1 vs day 5); *P<0.05; **P<0.01. Symptoms: A, Appetite decrease; B, Dyspnoea; C, Mucus production; D, Cough presence; Total (clinical score/4 points), sum A-D; 1, present symptom; 0, absent symptom. SD, standard deviation.
diagnosis, 4/6 patients had evidence of atelectasis. In these children, AS decreased from 2.5 (1–4) to 1.25 (2–3) points ($P = 0.34$, NS). Three patients (#2, #3 and #6) had improved AS with IPV while one had worsened AS (#5). CXR data are shown in Table 2. Three atelectatic children had evidence of calcifications, perhaps related to a previous history of tuberculosis (#1, #3 and #6) and with presence of nodules possibly causing compression in surrounding lung tissue. These calcifications remained after CXR improvement. Retrospectively, subject #1 was diagnosed with retrocardial bronchopneumonia with costo-diaphragmatic sinus infiltration. This subject also improved his clinical and CXR image after 5 days IPV. Subject #4 did not show evidence of pneumopathy. Three children presented with an enlarged heart. Table 1 shows that all six patients had significantly improved SpO2 (93.2 ± 0.8 to 95.3 ± 0.8; $P = 0.002$) and clinical score (2.8 ± 0.9 to 0.8 ± 0.6, $P = 0.012$). After 5 days of IPV treatment, they were all estimated stable and could be discharged home. No adverse event or side-effect of IPV therapy was reported during the study.

**Discussion**

In Vietnam, CXR are difficult to obtain because patients’ parents have financial problems to pay for their child’s radiographs. Furthermore, it is not usual to perform routine control CXR in Vietnam. For these reasons, one must realize that the possibility of assessing IPV treatment with a CXR follow up was an exceptional opportunity.

The main finding of this study is that IPV did not show any adverse effect. As before, we did not meet any adverse events during and after IPV treatments. This is more important than it seems to be. Because the IPV circuit makes a noise when it dynamically moves the chest with intrapulmonary bursts of positive pressure, the treatment actually looks aggressive to inexperienced doctors, therapists, patients and families. This represents a considerable brake to IPV therapeutic diffusion, especially amongst the medical staff who are understandably afraid of possible side effects from IPV. Furthermore, barotraumatism is theoretically impossible. We believe that this study with IPV can contribute to reducing this false idea that dangerous side-effects can happen.

The IPV device was a safe treatment for atelectasis resolution in 3/4 patients. Patients recovered a normal SpO2 and a clinical stability after 5 days IPV, as judged by a normal appetite recovery and by significant progressive disappearance of the symptoms. As soon as children recovered stability, they could go home. From the radiographic analysis in the four atelectatic children, one child spectacularly recovered from atelectasis while another worsened. We did not understand why CXR worsened in the latter because it contradicted his clinical improvement. We can not exclude that this patient had a chronic CXR evidence of atelectasis. The two other cases had a mild but significant CXR improvement after 5 days IPV as shown by AS reduction. Decreasing AS was encouraging although not significant. Previous studies showed IPV efficiency in children with atelectasis. In the first and retrospective part of their study, Deakins and Chatburn reported that AS significantly decreased from 3 to 1 in a group of 46 children who received IPV. In the second part of their study, the authors prospectively investigated atelectasis improvement in 12 intubated ventilated children. They compared IPV method ($n = 7$; $AS = 2$) versus conventional CPT ($n = 5$; $AS = 2.3$) in a randomized controlled trial. Atelectasis score significantly reduced from 2.3 to 0.9 in the IPV group although AS was unchanged in the CPT group. According to the results of Deakins and Chatburn, IPV therapy in our study quickly improved CXR and clinical presentation in atelectatic children and AS reduced after 5 days treatment in 3/4 cases. Deakins and Chatburn reported that IPV treatment lasted only 34% of

<table>
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<th>Day of</th>
<th>Total atelectasis score</th>
<th>Calcification</th>
<th>Bronch-pneum</th>
<th>Atelectasis score left</th>
<th>Calcification</th>
<th>Atelectasis score right</th>
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<td>n</td>
<td>Day of X-ray</td>
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the non-IPV treatment length (2.1 vs 6.2 days, \( P < 0.05 \)).18 In 1996, Birnkrant et al. showed that CXR appearance improved within 48 h of starting IPV therapy in neuromuscular children.19 Quick improvement of illnesses which was observed in the present study is obviously a very significant therapeutic advantage, especially in Vietnam since families are often poor and cannot pay for long hospitalization. This seems to be paradoxical with the high cost of the IPV technique in a poor country, but one must know that IPV therapy is available at the same price as conventional CPT in Paediatric Hospital No.1.

The current atelectasis improvement with IPV can be explained by an increasing efficiency of the ventilation distribution into the lungs. From the literature, IPV has proved efficiency in providing equal or improved oxygenation and ventilation.26 Distal ventilation improvement is clearly a strategy to develop in atelectasis resolution. Moreover, IPV combines positive expiratory pressure effect with vibration and percussion effects. In non-cystic fibrosis children, IPV has proved at least equally beneficial as some other CPT in the treatment of atelectasis.18 This is very positive, since infants and newborns lack the ability to perform other CPT techniques requiring some active collaboration.7 As already reported by Langenderfer, IPV is easy to use with non-collaborative patients.7 In our study, none of the, per definition, non-collaborative infants had difficulty in performing IPV. We assume that IPV is mechanically well adapted to young children under the age of 8 years. During this growing period, infants and children present specific lung mechanisms such as elevated chest compliance, unstable thorax and easily obstructed upper airways.5 The oscillatory continuous positive airway pressure (OCPAP) delivered by IPV could improve airway stability and, therefore, reduce the trend for airway collapse in these patients.17 If the airways are mechanically maintained in inflated position by the OCPAP, local ventilation should be improved and mucus could probably migrate more easily from distal to proximal airways. Anyway, further physiological explanation is required for a better understanding of IPV therapeutic mechanisms.

In conclusion, no side-effects were observed with IPV delivered with a face mask in young atelectatic children. Although the study population was small and the study was uncontrolled, IPV was a safe therapy for atelectasis resolution in 3/4 children selected without chronic obstructive syndrome. Patients significantly recovered a stable clinical state and a normal arterial oxygenation. Furthermore, lung X-rays improved in 4/5 subjects and all the patients could go back home after 5 days IPV. This study contributes to highlighting the work of local professionals in the development of chest physiotherapy which is a recent physiotherapy discipline in Vietnam.

Acknowledgments

The authors wish to thank Dr F. Bird for the gift he made of the first IPV display in Vietnam in 1999. They also wish to thank our friends and colleagues from Amphore Vietnam (Aide Médicale et Paramédicale Humanitaire et Organisation de Rencontres et d’Enseignement au Vietnam) who took time and energy to contribute to the authors’ chest physiotherapy education program. Thanks to Didier Everarts, Jacques Joubert, Dily de Guigné and Tamara Gillon in the preparation of this study.

References


