A Comparison of Intrapulmonary Percussive Ventilation and Conventional Chest Physiotherapy for the Treatment of Atelectasis in the Pediatric Patient

Kathleen Deakins RRT and Robert L Chatburn RRT FAARC

OBJECTIVE: Compare intrapulmonary percussive ventilation (IPV) to conventional chest physiotherapy (CPT) and determine their effects on improving atelectasis and static compliance in pediatric patients. METHODS: We conducted a retrospective study of 46 patients who received IPV therapy with the Percussionator IPV-1 ventilator at frequencies of 180–220 cycles/min and pressures of 15–30 cm H_2O. Medicated aerosol therapy with albuterol 2.5 mg in 6 mL normal saline solution was delivered with each IPV treatment. Baseline and subsequent chest radiographs were evaluated by a pediatric radiologist. We used an ordinal scoring system to measure the degree of atelectasis to evaluate chest radiographs (4 = complete collapse, 0 = complete resolution). Then we conducted a prospective, randomized, controlled study of intubated and mechanically ventilated patients to compare changes in atelectasis and static compliance. Baseline and daily chest radiographs were evaluated using the same scoring system as in the retrospective pilot evaluation. Patients were ventilated in the volume-controlled, synchronized intermittent mandatory ventilation mode, with tidal volumes of 6–10 mL/kg. Patients were randomized to CPT (clapping and vibration) or IPV at frequencies of 180–220 cycles/min and pressures of 15–30 cm H_2O (equal to the peak pressures on the ventilator), with 6 mL of normal saline solution via medicated aerosol. Both treatments were given every 4 h and lasted 10–15 min. Static compliance measurements were calculated from exhaled tidal volumes and plateau pressures. RESULTS: In the retrospective study the median age of patients receiving IPV was 4.2 years and the median duration of IPV was 6.2 days. A change in atelectasis score from 3 to 1 ($p < 0.001$) was seen. In the randomized, controlled trial the median age of patients was 3.1 years. Atelectasis scores before treatment were comparable between the CPT and IPV groups (median 2.0 for both groups, $p = 0.530$). Atelectasis scores after treatment were unchanged in the CPT group (median 2.0, $p = 0.421$) but improved in the IPV group (median 1.0, $p = 0.026$). Treatment lasted an average of 6.2 days in the CPT group and 2.1 days in the IPV group ($p = 0.018$). Neither group showed any change in static compliance following treatment. CONCLUSIONS: In the retrospective study a clinically important improvement in atelectasis was seen in patients who received IPV therapy. In the controlled, clinical trial the IPV group showed more clinically important improvement in atelectasis than the CPT group. IPV is a safe and effective method of alternative airway clearance and can be used on patients with artificial airways. *Key words: intrapulmonary percussive ventilation, chest physiotherapy, atelectasis, pediatric.* [Respir Care 2002;47(10):1162–1167]

Introduction

Airway clearance modalities are used to increase the effectiveness of cough, assist in mobilizing secretions, resolve atelectasis, and improve ventilation and oxygenation.[1] Conventional chest physiotherapy (CPT) methods include clapping, vibration, and postural drainage, which promote mobilization of secretions and improve cough in patients with atelectasis. Clinical practice guidelines have been es-

Kathleen Deakins RRT is affiliated with the Respiratory Care Department, Rainbow Babies and Children's Hospital, Cleveland, Ohio. Robert L Chatburn RRT FAARC is affiliated with the Respiratory Care Department, Rainbow Babies and Children's Hospital, Cleveland, Ohio, and with the Department of Pediatrics, Case Western Reserve University, Cleveland, Ohio.

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Correspondence: Robert L Chatburn RRT FAARC, Department of Respiratory Care, University Hospitals of Cleveland, 11100 Euclid Avenue Cleveland, Ohio 44106. Email: robert.chatburn@uhhs.com.

tablished for CPT and positive expiratory pressure (PEP). Oscillatory PEP (using either the Flutter valve or the Acapella device), high-frequency chest wall compression (HFCWC), and intrapulmonary percussive ventilation (IPV) are newer therapies awaiting the development of clinical practice guidelines.[2,3] Pediatric applications of airway clearance therapies include all of the currently established adult modalities. Selection of appropriate therapy is based on the patient's clinical presentation, the indications for treatment, and the patient's ability to perform the therapy.

IPV is the delivery of high frequency, low-volume, positive-pressure breaths in the range of 100–300 cycles/min. This mode of CPT creates an internal percussion effect on the lungs as they are held in the state of partial inspiration.[4] IPV is administered with the Intrapulmonary Percussionator IPV-1 ventilator (Percussionaire, Sandpoint, Idaho) via mouthpiece, mask, or artificial airway. Early experiences with IPV for cystic fibrosis and chronic obstructive lung disease demonstrated effective secretion mobilization, improved atelectasis, and enhanced oxygenation.[1] IPV was introduced in the mid-1980s as an airway clearance modality and an adjunct to standard practice with adults. It entered pediatric practice in the 1990s. To date there have been no safety and efficacy studies of IPV for airway clearance in intubated and mechanically ventilated pediatric patients.

Methods

We conducted 2 studies using IPV with pediatric patients. The first study was a retrospective evaluation to determine if IPV showed any radiographic evidence of clinical improvement of atelectasis or had adverse effects. Positive results from the retrospective study led to a randomized, controlled trial comparing the effects of IPV to standard CPT and postural drainage. We hypothesized that IPV would reduce atelectasis and improve static compliance.

Retrospective Study

This study evaluated pediatric patients in the Rainbow Babies and Children's Hospital pediatric intensive care unit, rehabilitation unit, and acute care areas. We studied patients who had radiographic evidence of atelectasis. IPV was ordered at the physician's discretion as an alternative to CPT. Patients receiving IPV were assigned a baseline "atelectasis score" (Table 1). Atelectasis was characterized by collapse of lung segments. Collapse was identified by the presence of at least 1 of the following: mediastinal shift toward the affected side, elevation of the hemidiaphragm on the affected side, identification of the interlobar fissure on the affected side, and (in most severe cases) reduction of intercostal spaces on the affected side.

Table 1. Atelectasis Scoring System

Score	Description
0	Complete resolution of collapse
1	Partial collapse of 1 segment or lobe
2	Partial collapse of ≥ 2 segments or lobes
3	Complete collapse of 1 segment or lobe
4	Complete collapse of ≥ 2 segments or lobes

Partial collapse was defined as linear densities extending from the mediastinum without shift, representing segmental collapse. Complete collapse was defined as presence of mediastinal shift toward the collapse, with elevation of the hemidiaphragm and the presence of air bronchograms on the affected side.

Patients received IPV under the direction of a physician. IPV was administered with a Percussionator IPV-1 ventilator at frequencies ranging from 180–220 cycles/min and pressures of 15–30 cm H_2O. An aerosol consisting of 2.5 mg albuterol and 6 mL of normal saline solution was nebulized with each treatment. Treatments were administered every 4–6 h, as ordered by the physician. The duration of treatment was determined by the amount of time required for the medication to be nebulized, usually about 10 min. Atelectasis scores were obtained upon reevaluation of daily chest radiographs.

Randomized Controlled Trial

The follow-up study was a prospective, randomized, controlled comparison of CPT and IPV administered for the treatment of atelectasis in a group of intubated and mechanically ventilated pediatric patients. The study protocol was approved by the hospital institutional review board, and parental consent was obtained prior to randomization or initiation into the study. Entry criteria included:

- Intubation and mechanical ventilation in the pediatric intensive care unit
- Evidence of atelectasis on chest radiograph
- A minimum patient weight of 3 kg

We arrived at the 3 kg minimum from the retrospective evaluation, in which 2 patients < 3 kg experienced hypotension during the IPV treatments.

Excluded from the study were patients who were febrile, who had secretion cultures positive for bacteria, who had pulmonary air leak, or who had other pulmonary diseases accounting for infiltrates (eg, pneumonia). Subjects were randomized to CPT or IPV by drawing sealed envelopes containing the treatment type, which created an equal and independent chance of being selected to one or the other treatment.[5]

The experimental protocol was initiated following randomization. Baseline data, including blood oxygen saturation (measured via pulse oximetry), blood pressure, breath sounds, and respiratory rate, were recorded before and after each treatment. Routine daily chest radiographs were obtained and atelectasis scores (using the ordinal radiology score system used in the pilot study) were assigned daily by a pediatric radiologist in consultation with a pediatric intensive care physician, both blinded to the type of treatment the patient received. All of the randomized patients were maintained on a Servo 900C ventilator (Siemens, Danvers, Massachusetts) for the duration of the study.

The following ventilation parameters were maintained during the study period: volume-controlled, synchronized intermittent mandatory ventilation; positive end-expiratory pressure 5 cm H_2O; tidal volume 6–10 mL/kg; and respiratory frequency determined by the patient's age and underlying clinical condition. Exhaled tidal volume and plateau pressures were measured with a respiratory profile monitor (CO_2SMO Plus! Novametrix Medical Systems, Wallingford, Connecticut), and static compliance was calculated from those values, as follows:

$$C_{stat} = \frac{V_T(mL)}{P_{plat}(cm\ H_2O) - PEEP(cm\ H_2O)}$$

in which C_{stat} is static compliance, V_T is tidal volume, P_{plat} is plateau pressure, and PEEP is positive end-expiratory pressure. Plateau pressure was measured by depressing and holding the inspiratory pause button on the Servo 900C at end inspiration.

Therapeutic Modalities

Patients randomized to conventional treatment received CPT for 10–15 min every 4 hours, administered by a respiratory therapist. CPT consisted of percussion, clapping, and vibration over areas of atelectasis. All patients were suctioned at the completion of each treatment.

Patients randomized to IPV received treatments every 4 h. The treatment involved removing the Servo 900C ventilator circuit tubing from the endotracheal tube adapter and attaching the IPV machine's tubing to the endotracheal tube adapter. During IPV, patients were maintained in the supine position. Treatment settings were determined prior to initiation of treatment. IPV pressure settings were set equal to the peak pressures observed during routine mechanical ventilation (15–30 cm H_2O). The frequency was determined by adjusting the impact control knob to a corresponding frequency that was manually counted at 180–220 cycles/min. IPV treatments were given with 6 mL of normal saline solution and lasted 10 min.

Although bronchodilators are known to increase airway caliber and cilia beat frequency and to enhance mucus clearance, they were not used in this study. Bronchodilators were avoided to allow objective evaluation of the effectiveness of the therapy, without possibly confounding results by the administration of medication. Upon initiating therapy, chest rise was observed and breath sounds were assessed. IPV intervals lasted 20 s, followed by 5–10 s pauses. Additional pauses were interspersed when the patient needed suctioning or during episodes of coughing.

Following both types of treatment, vital signs, treatment variables, static compliance, and adverse reactions were recorded. Patients exited the study when atelectasis had resolved on chest radiograph (as indicated by an atelectasis score of zero) or on extubation.

The Mann-Whitney rank sum test was used to compare the scores from before and after treatment, and differences were considered statistically significant when $p \leq 0.05$.

Results

Retrospective Study

Forty-six patients were evaluated in the retrospective study, ranging in age from 1 month to 15 years (median age 4.2 y). Forty-one patients (90%) received IPV treatments through the artificial airway. Five patients (10%) received IPV via mask. A significant improvement in atelectasis score was seen (from 3 to 1, $p < 0.001$). The median duration of treatment in this study was 6.2 days. No adverse effects were detected from the IPV treatment or from the administration of bronchodilators.

Randomized Controlled Trial

The randomized, controlled study enrolled 12 participants (5 in the CPT group, 7 in the IPV group), with ages ranging from 7 weeks to 14 years (Table 2). The endotracheal tube sizes used in the study participants ranged from 3.0 to 7.0 mm internal diameter, with 4.0 being the most prevalent. The CPT group showed no change in atelectasis score with treatment ($p = 0.421$), but the IPV group showed improvement, from 2.3 to 0.9 ($p = 0.026$). The duration of treatment to the resolution of atelectasis was significantly less in the IPV group (3.1 vs 6.2 d, $p = 0.018$). There were no significant differences in static compliance, saturation, or respiratory rate with treatment. Neither group experienced any adverse effects as a result of the treatments.

Discussion

A healthy individual accomplishes airway clearance through mucociliary action and effective cough. Inherent airway clearance mechanisms are efficient under normal

Table 2. Raw Data

Patient	Atelectasis Score		Static Compliance (mL/cm H_2O)		S_{pO_2} (%)		f (breaths/min)		Treatment Duration (d)	Weight (kg)	Age
	Before*	After	Before	After	Before	After	Before	After			
CPT 1	2	2	1.9	1.9	93	95	44	52	5	4.5	4 mo
CPT 2	2	2	2.1	1.5	92	93	36	32	7	3	2 mo
CPT 3	2	2	2.4	3	95	95	42	48	8	5	3.5 mo
CPT 4	1	4	36.4	34.6	91	92	18	14	4	56	14 y
CPT 5	3	3	7	8.3	93	93	24	28	7	16	3 y
CPT Mean	2.0	2.6	10.0	9.9	92.8	93.6	32.8	34.8	6.2	16.9	–
IPV 1	3	1	2	2.8	91	92	36	33	2	3	3 mo
IPV 2	2	0	3.5	4	93	93	26	28	2	10	22 mo
IPV 3	3	3	2.3	3	92	95	44	42	4	4	4 mo
IPV 4	1	0	1.3	1.6	94	95	38	36	2	3.8	7 wk
IPV 5	2	1	7.6	6.6	93	99	26	28	3	7.8	14 mo
IPV 6	2	1	6.5	7.2	90	93	36	33	2	8	18 mo
IPV 7	3	0	7.7	8.3	94	94	24	25	7	16	3 y
IPV Mean	2.3	0.9	4.4	4.8	92.4	94.4	32.9	32.1	3.1	7.5	–

f = respiratory rate
*Values labeled "Before" were obtained after the first treatment. Values labeled "After" were obtained after the last treatment, when the patient exited the study.
S_{pO_2} = oxygen saturation measured via pulse oximetry.
CPT = chest physiotherapy
IPV = intrapulmonary percussive ventilation

conditions. Mucus movement is accomplished by the mucociliary escalator, which propels mucus from deep in the lung toward the large airways.[6] Mucus is expelled from the airway by swallowing or cough.

Abnormal physical conditions such as primary respiratory muscle weakness, physical deformities of the chest wall found in restrictive lung disease, genetic multisystem disorders with primary cilia defects, or the presence of atelectasis caused by mucus plugging pose a challenge to normal airway clearance mechanisms. Patients who are intubated and mechanically ventilated share similar inadequacies in mobilizing and removing secretions. A weak, ineffective cough can be caused by physical restriction and the presence of an endotracheal tube, which inhibits the ability to clear secretions. Any breakdown in the normal airway clearance mechanism can result in secretion retention. Airway obstruction (partial or complete) may contribute to atelectasis and can result in inadequate ventilation and gas exchange.[6] The goal of airway clearance therapy is to promote improvement in cough and to facilitate expectoration by using techniques and modalities that can meet specific airway clearance objectives.

Historically, CPT has been the accepted standard for airway clearance therapy in pediatric patients and cystic fibrosis patients.[7] In recent years alternatives have become available and are often compared to conventional CPT for the amount of sputum produced and their ability to re-expand areas of atelectasis and improve gas exchange. In CPT, positioning, gravity drainage, and percussion and vibration are effective in moving secretions from the small to the large airways, allowing sputum expectoration by cough. CPT in combination with kinetic therapy has been shown to be effective in reducing atelectasis in critically ill patients.[8] Kinetic therapy used in combination with bronchodilators may parallel the results of IPV with kinetic therapy for the resolution of atelectasis. We did not use kinetic therapy on any patient included in the present studies.

Positive expiratory pressure, another modality that came from Europe, was designed to promote secretion clearance by active exhalation through a flow resister. The positive pressure created in the airway on exhalation assists in opening the small airways, allowing mobilization of secretions and cough. PEP was compared to CPT in multiple airway clearance modality evaluations of patients as young as 3 years, with positive results seen primarily in postoperative atelectasis patients and cystic fibrosis patients.[6] Oscillatory PEP devices such as the Flutter valve and the Acapella device are designed to vibrate the airway walls and thus promote mucus clearance while maintaining a degree of PEP to keep airways open during exhalation. The Flutter valve is gravity dependent, unlike the Acapella, which is not dependent on patient position and can be used with children, with a mask. Adult and pediatric patients

can operate the Flutter or the Acapella independent of a caregiver.

HFCWC (with *The Vest*) is another modality that can be performed independently; it is an acceptable alternative to CPT and has been successfully used on mechanically ventilated patients.[9] IPV, a combination of PEP or Flutter and aerosol therapy, allows chest percussion with low tidal volume, promoting mobilization of secretions from small to large airways and also promoting cough. IPV via mouthpiece, mask, or artificial airway is in its early stages of development for pediatric patients.

Studies comparing IPV, HFCWC, and CPT revealed that IPV was as effective as traditional CPT combined with aerosol therapy. Langenderfer compared the alternative airway clearance modalities such as HFCWC, Flutter, PEP, and IPV to conventional CPT and concluded that IPV and HFCWC uniquely benefited patients who can't perform other therapies.[1] Reports of IPV for conditions other than cystic fibrosis found radiographic improvement in segmental atelectasis within 48 hours of initiating treatment.[4] Homnick et al presented a comparative trial of IPV versus CPT, involving 16 cystic fibrosis patients. They concluded that IPV was as effective as CPT combined with aerosol therapy in protecting lung function.[7]

The results from our retrospective study were similar to results from prior studies, including a clinically important improvement in atelectasis when using IPV therapy as the airway clearance modality. To better understand and validate the clinical effects of IPV, the randomized, controlled trial was conducted. Our clinical trial paralleled other trials by comparing IPV to CPT and postural drainage. Chest radiographs provided objective measurements for assessing changes in atelectasis score from baseline and helped guide and determine the duration of therapy. In addition we hypothesized that if atelectasis improved, lung volume would increase and therefore static compliance might be affected. The fact that compliance showed no change may be explained in a variety of ways, including the fact that simply increasing lung volume does not necessarily change the pressure-volume characteristics (the curve may simply be shifted upwards). Also, the effect on lung volume may have been too small to affect compliance.

Limitations of the randomized, controlled trial included relatively small sample size and a lack of control for severity of illness or any other aspect of care. However, in the CPT group, even excluding the patient who worsened following treatment, the results would have been the same because no patient showed improvement in atelectasis score. On the other hand, all but 1 IPV patient showed improvement following treatment. Though a Type I error could have been made in concluding that there was a difference in atelectasis scores, the probability of that event is < 1 in 1,000. Also, there was no difference between the initial atelectasis scores of the CPT and IPV groups (median 2.0 vs 2.0, $p = 0.530$), which leads us to believe that the 2 groups were comparable. The atelectasis score is a subjective evaluation, which could cause some inconsistency in results. However, the physicians responsible for assigning the scores were blinded to the treatment type, decreasing the chance of bias.

If a further study is undertaken based on our data, we would like to know the sample size required to show a difference in treatment effect of a given size while maintaining a statistical power of at least 0.80. Unfortunately there appears to be no power analysis procedure for comparing median values of ordinal data.[10,11] One alternative is to postulate that the CPT group and the IPV group have an equal probability of showing an improved atelectasis score after treatment (ie, the null hypothesis). We define a clinically important change in atelectasis score as being 1.0 unit. We further hypothesize that the probability of a score improving by at least 1.0 unit by chance is 0.50. We can now do a power analysis for the difference between 2 proportions, assuming 2 tails, with α set at 0.05 and power at 0.80. Our data suggest that 86% of patients treated with IPV will show an improvement of at least 1.0 unit. To detect that proportion compared to a control group in which 50% of the patients showed an improvement of 1.0 unit, we would need to enroll 25 patients in each group. If only 10% of the control group showed improvement, we would need to enroll only 6 patients in each group to get a power of 0.85. Given that none of the control patients showed any improvement in our study, the smaller sample size might be achievable.

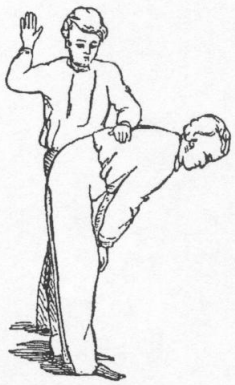
Conclusions

The results of this study suggest that IPV is a more effective method of re-expanding areas of atelectasis in ventilated patients than is conventional CPT. IPV may achieve results in about half the number of treatment days as CPT, with no adverse reactions. Given that both CPT and IPV treatments last 10–15 min, we speculate that IPV may be associated with a lower cost of care, through reduced labor hours.

REFERENCES

1. Langenderfer B. Alternatives to percussion and postural drainage. A review of mucus clearance therapies: percussion and postural drainage, autogenic drainage, positive expiratory pressure, flutter valve, intrapulmonary percussive ventilation, and high frequency chest compression with the ThAIRapy Vest. J Cardiopulm Rehabil 1998;18(4): 283–289.

2. American Association for Respiratory Care. AARC Clinical Practice Guideline: Postural drainage therapy. Respir Care 1991;36(12):1418–1426.
3. American Association for Respiratory Care. AARC Clinical Practice Guideline: Use of positive airway pressure adjuncts to bronchial hygiene therapy. Respir Care 1993;38(5):516–521.
4. Birkrandt DJ, Pope JF, Lewarski J, Stegmaier J, Besunder JB. Persistent pulmonary consolidation treated with intrapulmonary percussive ventilation: a preliminary report. Pediatr Pulmonol 1996;21(4):246–249.
5. Rau J. Sampling and research designs. In: Chatburn RL, Craig KC, editors. Fundamentals of respiratory care research. Norwalk: Appleton & Lange; 1998:133–154.
6. Hardy KA. A review of airway clearance: new techniques, indications, and recommendations. Respir Care 1994;39(5):440–452; discussion 453–455.
7. Homnick D, White F, de Castro C. Comparison of effects of an intrapulmonary percussive ventilator to standard aerosol and chest physiotherapy in the treatment of cystic fibrosis. Pediatr Pulmonol 1995;20(1):50–55.
8. Raoof S, Chowdrey N, Feuerman M, King A, Sriraman R, Khan FA. Effect of combined kinetic therapy and percussion therapy on the resolution of atelectasis in critically ill patients. Chest 1999;115(6):1658–1666.
9. Whitman J, Van Beusekom R, Olson S, Worm M, Indihar F. Preliminary evaluation of high frequency chest compression for secretion clearance in mechanically ventilated patients. Respir Care 1993:38(10):1081–1087.
10. Cohen J. Statistical power analysis for the behavioral sciences. New York: Academic Press; 1977.
11. Kraemer HC, Thiemann S. How many subjects: statistical power analysis in research. Newbury Park: Sage Publications; 1987.



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